PERIODICAL ROOM
GENERAL LIBRARY
UNIV. OF MICH.

FEB 26 1934

THE MARCH SCIENTIFIC MONTHLY

EDITED BY J. MCKEEN CATTELL

THE PROBLEMS OF THE DESERT. DR. FORREST SHREVE 199
RACING CAPACITY IN THE THOROUGHBRED HORSE, PART I. DR. HARRY H. LAUGHLIN 210
THE CONQUEST OF MALARIA. PROFESSOR ARTHUR L. BEELEY 223
THE ORGANIZATION OF INCA SOCIETY. PROFESSOR GEORGE PETER MURDOCK 231
WHERE IS PHYSICS GOING? PROFESSOR R. B. LINDSAY 240
MODERN SCIENCE, THE HOPE OF CIVILIZATION. DR. M. LUCKIESH 251
WHAT'S THE MATTER WITH WHEAT? DR. C. G. WILLIAMS 253
THE SCIENTIFIC JOURNAL, 1665–1730. SHERMAN B. BARNES 257
THE PHYSICAL GOETHE. DR. JAMES FREDERICK ROGERS 261
SCIENCE SERVICE RADIO TALKS:
COLOR CHANGES IN ANIMALS. PROFESSOR EARLE B. PERKINS 264
FRIENDLY GERMS. DR. W. LEE LEWIS 267
MOSSES. DR. A. J. GROUT 270
RESEARCH IN THE BUREAU OF DAIRY INDUSTRY. O. E. REED 274
THE PROGRESS OF SCIENCE:
The Presentation of the Edison Medal to Professor Kennelly; Administration of the Weather Bureau; Fritz Haber; Man—Past and Present—in the Field Museum; High Altitude Weather Observations 286

THE SCIENCE PRESS
LANCASTER, PA.—GRAND CENTRAL TERMINAL, N. Y. CITY—GARRISON, N. Y.

Yearly Subscription $5.00 Single Copies 50 cents

NEW BOOKS OF SCIENTIFIC INTEREST

Algebraic Functions. GILBERT A. BLISS. ix + 218 pp. $3.00. American Mathematical Society.

A discussion of the three methods by which the theory of algebraic functions has been developed, designated as transcendental, algebraic-geometric and arithmetic. The book is introductory in character and not a comprehensive treatise.

Principles of Geometry. Volume V. Analytical Principles of the Theory of Curves. H. F. BAKER. x + 247 pp. $4.50. Cambridge University Press.

This volume is an account of the analytic principles of the theory of curves, of the rational functions belonging thereto and of the integrals of these functions, with the elements of the theory of the Riemann surfaces.

Physical Optics. ROBERT W. WOOD. Third Edition. xvi + 846 pp. Illustrated. $7.50. Macmillan.

A technical discussion of the phenomena of light, emphasizing the experimental side of the subject. The author has made a special attempt to present a physical picture of processes usually described by equations.

Riddles of Science. SIR J. ARTHUR THOMSON. 378 pp. Illustrated. $1.00. Liveright.

The author presents thought-provoking problems in almost every field of biology and then proceeds to answer them in the light of the most recent scientific knowledge. The book has been written in non-technical language.

The Evolution of the Vertebral Column. H. F. GADOW. xiv + 356 pp. Illustrated. $6.75. Cambridge University.

This posthumous contribution to the study of vertebrate phylogeny aims to put together the evidence of the various lines of development of the vertebrae as a guide to the general morphological scheme of vertebrate evolution.

The Biology of Bacteria. ARTHUR T. HENRICI. x + 472 pp. Illustrated. $3.60. Heath.

This introduction to general microbiology is intended as an introductory textbook for college students. While dealing mainly with bacteria, a considerable part of the work has to do with protozoa and fungi, and other forms of microbic life.

Termites and Termite Control. CHARLES A. KOFOID, Editor. xxv + 734 pp. Illustrated. $5.00. University of California.

This report to the Termite Investigations Committee discusses the biology of termites and contains recommendations for prevention and control of termite damage by methods of construction and the use of chemically treated and unpalatable woods.

China's Geographic Foundations. GEORGE B. CRESSEY. xvii + 436 pp. Illustrated. $4.00. McGraw-Hill.

This survey of China and its inhabitants presents an interpretation of the adjustments which the Chinese have made to their environment and an analysis of the varied characteristics of the cultural and physical landscape.

Culinary Herbs and Condiments. M. GRIEVE. 209 pp. $2.00. Harcourt, Brace.

A catalogue of the culinary herbs, including a description of the herbs and details concerning their cultivation, comprises the first part of this book. Recipes for herbal beverages and a section on condiments complete the work.

Contagious Diseases. W. W. BAUER. 218 + vii pp. $2.00. Knopf.

This is a handbook on the nature of communicable diseases, their prevention, occurrence and treatment. It has been written especially for the layman by the director of the Bureau of Health and Public Instruction of the American Medical Association.

Applied Psychology. RICHARD W. HUSBAND. xv + 654 pp. Illustrated. $2.50. Harpers.

This work is intended primarily as a textbook for college courses in applied psychology. The author has attempted to present and evaluate the opinions held by leading authorities in many fields of practical psychology.

Manual of the Southeastern Flora. JOHN KUNKEL SMALL. xxii + 1554 pp. Illustrated. $10.50. Science Press Printing Company.

Descriptions of the seed-plants growing naturally in North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Tennessee and Eastern Louisiana.

Urban Society. NOEL P. GIST and L. A. HALBERT. xv + 724 pp. $3.50. Crowell.

The phenomenon of urbanism is discussed under the following headings: The Rise of Urbanism, Distributive and Selective Aspects of the City, Social Relationships, Organization of Life and Planning and Control of Urban Society.

Culture in the South. W. T. COUCH, Editor. xiv + 711 pp. $4.00. University of North Carolina.

Thirty-one students of the South have each contributed a chapter to this volume. Together they present a picture of the more important aspects of life in the present South and their historic background.

THE SCIENTIFIC MONTHLY

MARCH, 1934

THE PROBLEMS OF THE DESERT

By Dr. FORREST SHREVE

DESERT LABORATORY OF THE CARNEGIE INSTITUTION OF WASHINGTON

THE man of practical affairs looks ruefully at the desert as a great waste place which should be put to human use as speedily as possible. Almost invariably his conception of utility is the prevailing one, which concerns only the physical welfare of man. He sees the possible extension of agriculture, the maintenance of improved grazing ranges, the utilization of natural desert products or the conversion of solar energy into commercially useful forms. The more philosophical student of human needs can see in the desert many uses of a wholly different type—humanistic, intellectual and esthetic. He can see the desirability of having a little-coveted region in which it is possible for people to dwell simply and cheaply, with the opportunity to wander, to think, to paint, to study or to write without noise and disturbance. The economist would doubtless agree that the value of the desert as a living place, a source of inspiration, a field of scientific work, is worth many times its marginal value in the world of commodities.

Many features of our civilization were developed in the remote past by desert people of the Old World. It appears highly probable that the human race owes as much of its advancement to the dwellers in the arid lands around the Mediterranean as it does to those of the cool and humid portions of Europe and Asia. In America the aborigines had made their greatest advances in the communities of the desert southwestern states and in the arid portions of Mexico and Peru. The present generation, equipped with the tools of research, faces the duty of learning to know the desert as fully as possible. It must unravel the tangle of reasons for its having been a favorable place for advancement, it must investigate the practical utilities of the desert and must evaluate its higher potentialities for service. It will then remain for the future to determine the ultimate place of the desert in civilization.

In considering the problems of the desert the line of vision falls directly across the boundaries which separate the conventional fields of scientific endeavor. Peculiar to the desert are many of its physiographic processes, its climatic influences, the distribution and character of ground water and soils, the regimen of its streams, the structure of its plants, the behavior of its animals and the culture of its men. A full view of the problems of the desert embraces inquiries into all these. The study of the desert belongs in part to many sciences. Since the aim of eremology is to understand the desert, its history, processes and life, a close interlocking is essential in the work which these sciences contribute to the solution of its problems. As a regional rather than a topical subject eremology takes its place as

a part of the great field of geography. Primarily, both of them deal with natural features, but the ultimate concern of each is the relation of these features to man.

Many of the problems of the desert are intrinsic, while others are common to the desert and to moister regions, but can be attacked in a more effective manner under the clear-cut extremes of the desert. Indeed, it is not always possible to delimit the problems of the arid lands from those of the semi-arid ones, and there is no great importance in doing so. The very term "desert" is a relative one, since the surface of the earth presents a great variety of arid areas, ranging from the most extreme rainless wastes of wind-blown sand or barren rock to regions with a moderate rainfall and a surprising amount of plant and animal life. Throughout this entire gamut of aridity the low and irregular rainfall is the most important item in the physical conditions. However, there is no particular minimum of rainfall and no other single criterion that will serve to distinguish a desert. Ten inches of rain in temperate latitudes will give better conditions than twenty inches in the subtropics. The altitude, the topographic features, the character of the soil, the proximity of the sea and the percentage of cloudiness all serve to modify conditions as much as differences in rainfall do. An adequate definition of desert must be a composite one, embracing both its causal and sequential features. It must be based on the degree to which a scanty and irregular water supply becomes an item of first moment in the life of plants and animals. Finally, its human aspects must be stressed, as has often been done by defining it as any region in which irrigation is essential to agriculture and to permanent settlement based on it. In speaking of the frontiers on which aridity has checked the spread of civilization, Isaiah Bowman has well said: "These are the regions where environment conspicuously affects the lives of men."

The principal aspects of desert investigation are exploration, geological and physiographic work, the study of stream history, of soils, of climatic conditions, of plants and of animals.

ALKALINE PLAINS

OF OTERO BASIN, NEW MEXICO, BEARING ONLY SALTBUSH AND SCATTERED TUFTS OF GRASS.

OUTWASH PLAIN IN THE TULE DESERT,

NEAR THE INTERNATIONAL BOUNDARY IN SOUTHWESTERN ARIZONA. IN THIS REGION A RAINFALL OF 6 TO 8 INCHES SUPPORTS A REMARKABLY RICH PLANT AND ANIMAL LIFE.

Scarcely less important than all these is the study of the natural history of man in desert environments, both in the past and the present. The anthropologist and the archeologist can here unite in a study of the habits, culture and practises of early and recent desert races, and the physiologist and geneticist can investigate the influences of the desert environment and the characteristics it may have engendered.

Geographical exploration has shown the location of the deserts of the world and has outlined their boundaries, at the same time that it has done much toward the mapping of their mountains, streamways and other features. In some of the largest and most arid regions, however, there still remains much to be done in the primary phases of geographical work. The investigation of the geological features has been thorough in a few restricted localities and extremely cursory or wholly lacking in extensive areas. Much additional work is needed and promises rich returns in both stratigraphy and paleontology, as is amply illustrated by the results secured by the American Museum of Natural History in Mongolia.

The features of land form and physiographic process which are characteristic of desert areas have received considerable study in Asia, Africa and America. The recent important contributions in this field by Kirk Bryan, Douglas Johnson, Eliot Blackwelder and others show how promising are the possibilities of further work in arid regions. The history of drainage ways and the influences of climate on erosion and deposition need further exhaustive work, particularly with reference to the outcome of climatic fluctuations. More detailed study is needed in additional regions as to the comparative rôle of wind and water in physiographic processes.

In climatology the desert has been

sampled, but its conditions have not been thoroughly investigated except in a few widely separated places. The extremes of drought and temperature are better known than their frequence and seasonal distribution. Much has been published on the most astonishing features of certain accessible places, at the same time that very few data are available to show the stages of climatic change that are to be encountered in passing from the heart of the desert across its boundaries into the grassland or savanna by which it is bordered. Every general climatological text betrays the inadequate knowledge of the arid regions, as contrasted with the humid ones. For example, in Geiger's illuminating work on the lowest level of the air, "Das Klima der Bodennahen Luftschicht," little is found about the desert, the very region in which the lowest layers of the atmosphere show the greatest departure from the higher ones. The arid regions, in fact, provide splendid material for effective study of meteorological processes. In them are found rapid changes in temperature of the soil, vigorous convectional movements in the air, sharply contrasting droughts and downpours, all occurring under conditions such that cause and effect can be most easily followed. The study of light and of solar radiation in the desert is just beginning, in spite of the fact that sunshine is the greatest and most distinctive natural resource of the desert.

Some of the most interesting and at the same time most complex problems of the desert relate to the plant and animal life which shows itself to be so well adjusted to conditions of great aridity. There is no epic more thrilling than the story of the keenly pursued lines of investigation that gave us our knowledge of the ascent of plants and animals. The morphologist has shown that the sea was the place of origin of life and has traced the lines of development of its organisms with convincing accuracy. The morphologist and the paleontologist have united to give us a picture of the emergence of life from the ocean and its establishment in swamps, marshes and rainy jungles, followed by its rapid adjustment to solid land. An equally thrilling story awaits the reader of the future when it becomes possible for him to have the full narrative of the conquest of the desert by living things. The emigration of life from the sea to the moist jungle is scarcely more astounding than its hegira from the moist jungle to the desert.

The physical sciences seem to have sketched a fairly clear picture of the characteristic phenomena of the desert in their fields when the work that they have accomplished is contrasted with the imperfect outlines of the picture that biology has been attempting to draw.

The geologist has furnished satisfactory evidence that there have been deserts in past epochs, probably extensive and pronounced ones, but he has been compelled to draw his conclusions mainly from the physical character of the deposits then laid down. Deserts have existed since Permian time, appearing and disappearing in different parts of the world. The evidences of some of them are found in regions which are now desert. Some of the most arid parts of the world have been so for a very long time, but not a great deal is known as to the actual continuity of desert conditions or the possibilities for the persistence of the same types of life through such long periods. The fact that the desert offers such poor conditions for the preservation and fossilization of living remains has resulted in a relatively small contribution from paleontology toward the history of desert areas. Indeed, the fact that moist regions offer such good conditions for the preservation of a biological record may be responsible for some exaggeration in estimating the extent to which moist conditions have prevailed since Paleozoic time.

SHORT-LIVED HERBACEOUS PLANTS

IN SOUTHERN ARIZONA A PERIOD OF COPIOUS RAIN IS FOLLOWED BY THE APPEARANCE OF MANY OF THESE.

The history of the origin and development of the biota of the desert, that is, of its animals and plants considered collectively, constitutes a problem which is largely a distinct one for each of the great continental desert areas. It has long been known that there are very few species of plants or animals common to the arid lands of America, Africa, Asia and Australia. At the present time these deserts are effectively isolated from each other by the sea or by humid regions. Certain relationships may be cited between the deserts of North and South America and between those of North and South Africa, at the same time that there are a few slender threads of connection between America and Africa, and between Africa and Australia. Much stronger are the relationships between each of the desert areas and the warm humid regions which are nearest to them. It is clear that the deserts have been populated by races of plants and animals from near at hand, and only to a very slight extent by races from other deserts. In each of these great areas the same conditions have been encountered, and the same problems of adjustment have been met by organisms entering the desert from whatever source. Numerous stocks or races have been involved in the settlement of each great desert area. Numerous types and methods of adjustment to arid conditions have been developed. There is scarcely any warrant for saying that one of these adjustments is better than another, for each of them permits the persistence of the stock by which it has been developed. Doubtless there are many extinct types of adjustment, which failed in the double strug-

gle against other organisms and an adverse environment. An examination of the biota of any one of the great desert areas will disclose that there are very many cases in which the same general type of adjustment has been developed by unrelated stocks. Large roots in which water and food reserves are stored and protected by an extremely distasteful coating are to be found in the American deserts in four widely unrelated families of plants. Indeed, with respect to plants, there are very few structural or functional adjustments to the arid environment which are not known to occur in several families. Particular interest attaches to the parallel lines of development that have taken place in widely distant areas of similar character. The vegetation of South Africa offers many examples of analogy with that of North America, the euphorbias resembling the cacti, Aloe recalling Agave and Sarcocaulon suggesting Fouquieria.

The adjustments of an organism to arid conditions may be obvious or obscure. Few structural features would serve to distinguish the ants or the birds of the moist tropics from those of the desert. Certain beetles and reptiles might be readily recognized as desert forms, while others would not. Among the mammals of the desert it is almost wholly features of behavior rather than of structure that have enabled them to colonize the lands of high temperature and little water. Among plants it is easy to detect features of structure which serve to reduce water loss or to provide a reserve of water. There are many other obvious features which enable the plant to take advantage of periods of abundant moisture and to escape the difficulties of maintaining their water solvency during periods of great drought. However, an increasing number of cases is known in which plants exhibit differences in water requirement of which there is no hint in their structure. It appears, therefore, that the sure recognition of a desert organism can be based only on its occurrence in the desert, and that an interpretation of its adjustments can be secured only by investigations of its behavior, life history, structure and physiological characteristics, carried on under natural conditions. Desert work has been done in so few places that we have only superficial knowledge on which to base a comparison of the structural, functional and behavioristic features of the biota of the several desert areas of the world. It is an interesting commentary on the conservatism of science that a score of oceanographic institutions and over two hundred marine and fresh-water laboratories are devoted to the investigation of aquatic life and conditions, while there are only three small laboratories in the entire world in which the scientific problems of the desert are being pursued.

The one aspect in which investigation of desert life has reached a fairly satisfactory stage of advancement is the collecting, classification and naming of its plants and animals. Through the assembled results of taxonomic work it is possible to draw several conclusions. The desert has fewer species of plants than the moist regions, about the same number of species of birds and mammals, and a greater number of species of reptiles. The organisms of the desert show varying degrees of relationship to those of moist regions. Most of the species, many of the genera and a few of the families are distinctive. These degrees of relationship are unlike in America, Asia, Africa and Australia.

Only through close cooperation between the geologist and the biologist will it be possible to estimate the duration of arid conditions in the several great desert areas and to reconstruct the stages of earth history which have furnished the setting for the development of desert life. Thus only will it be possible to determine whether age, differences in

AN UNDRAINED BASIN IN THE MOHAVE DESERT, CALIFORNIA

ALMOST THE ENTIRE VEGETATION IS HERE FORMED BY ONLY TWO SPECIES OF PLANTS. IN THIS REGION THERE HAVE BEEN PERIODS OF THREE YEARS WITHOUT PRECIPITATION.

severity of conditions or other factors are responsible for the existence of far more highly specialized types of life in some deserts than in others.

Just as human "history is past politics," so is the history of the desert biota no more than a study of its distribution, the character of its environment and the nature of its responses to the conditions which prevailed at successive periods in the past. The relations that exist to-day, and are now under investigation, have been determined to a great extent by the conditions which existed yesterday and are now subject to investigation only by means which are indirect, inferential and incomplete. Attempts to unravel the problems of origin and history of desert life through faunistic and floristic work on the animals and plants of to-day will make successful progress only when conducted in close conjunction with the facts known in regard to the habitat, behavior and physiological characteristics of the biota, and with the maximum aid from the findings of developmental morphology and comparative anatomy.

Two fundamental questions underlie all inquiries regarding the adjustment of life to desert conditions. How does the organism handle its water, and how do conditions of intense and prolonged illumination affect its life processes? The answers to these questions will have much of common application to plants and animals. However, the plant bids fair to show a higher degree of qualitative adjustment to extreme conditions because of its immobility. The rodents of the desert have acute problems of food supply, but their relatively damp and cool underground homes protect them from extremes. An exposure of fifteen minutes to the midday sun is fatal to many of them. Birds, reptiles, insects and larger mammals are all out of sight at midday in the hot, dry seasons. Meanwhile the perennial plants are exposed to desiccation and illumination and either meet these conditions or perish.

The investigation of water relations has advanced further than that of light relations, because of its greater simplicity and surer physical background. Particularly in the case of plants has there been enough work to give a fair understanding of water loss and the relation of arid conditions to its daily and seasonal fluctuations, and also of water storage and the features of physiological behavior that are associated with it. In the investigation of the soil as a source of water for the plant, the entry of water into the plant, and the movements of water in its stem and other tissues, there is a large unworked field of great importance. Relatively little has been done on the water relations of animals. A comparison of the rôle of water in metabolism in the animal groups of the desert is not yet possible. The loss and requirement have been investigated in only a few forms. Many desert animals are known to take no liquid water, and our knowledge of their supply through moist or dry food is very incomplete. Terrestrial insects are exposed to higher temperatures than any other animals, but very little is known about their temperature relations and the bearing of these relations on their obviously low water requirement. In the case of both animals and plants it is important that the investigation of the relations of water, light and temperature be conducted in such a manner as to give adequate weight to the fact that these conditions are all operating concurrently and that the three have very close interrelations.

Considerable attention has been given to the obvious and easily studied features of structure which characterize desert plants, particularly those which may be interpreted as having to do with the conservation of water. Far more significant than any of these external devices is the ability of certain organisms to withstand the extremes of adverse conditions without possessing any

LOW VOLCANIC HILLS

ON THE WEST COAST OF MEXICO, NEAR PALMA, SONORA. THORNY, SMALL-LEAVED SHRUBS ARE THE PREVAILING PLANTS.

PLAINS NORTHWEST OF SUAKIN,

IN THE NUBIAN DESERT, WITH A VERY OPEN COVER OF THORNY TREES AND SHRUBS. PHOTOGRAPH BY D. T. MACDOUGAL.

of the external mechanisms which appear to be so important to certain of the higher plants. Particularly among the mosses and ferns are many cases in which the leaves are able to withstand prolonged desiccation without their protoplasts losing the ability quickly to resume activity when freshly supplied with water. The features of drought resistance may be studied in these plants or in some of the desert insects with bright prospects of fundamental results. The neglect of such problems has been due largely to the fact that the men who have had an opportunity to work in the desert have not been able to remain there for more than a few months. The investigator with limited time selects the problems that will give quick returns rather than the ones that promise fundamental results at the expense of many years of work.

An understanding of life under desert conditions can not be built up by the employment of any one restricted method of procedure. Although the problems involved are not, on the whole, so complicated as those of moist regions, and particularly the moist tropics, they can nevertheless be attacked with profit only by a broad investigative movement. Such an approach requires the employment of methods and outlooks from the entire range of biological science. The view-point of the old-fashioned naturalist is of great importance in studying the life histories and behavior of all groups of animals. The study of distribution must go hand in hand with that of the relation of organisms to environmental conditions. The study of structure must accompany the investigation of function. The study of function must lean heavily on the physical sciences. The solution of the intricate problems of the adjustment of life to desert conditions requires a closely interlocking utilization of the methods of all aspects of biological research.

The essential unity of desert problems has been strongly emphasized by the study of environmental conditions and of plant and animal life which has been

SANDY PLAINS BETWEEN KHARGA AND DAHKLA,

IN THE LIBYAN DESERT, WITH HILLS ERODED BY WIND-BLOWN SAND. HERE, AND IN SIMILAR SITUATIONS IN THE SAHARA, ARABIA AND THE DESERT OF GOBI, PLANT AND ANIMAL LIFE ARE AT THEIR MINIMUM FOR THE LAND SURFACE OF THE EARTH. PHOTOGRAPH BY D. T. MACDOUGAL.

carried on in the southwestern United States during the last 30 years. In many respects the plants are less profoundly influenced by each other than they are in moist regions, and more closely affected by the environment. The interrelations between the life and the environment are intimate and intricate. Every aspect of the desert is closely tied to every other aspect of it. The influences of the climate on physiographic and soil processes, the relation of these to vegetation, the influence of vegetation on the life and fate of animals, the manifold influences of animals upon plants, and the reciprocal effect of plant and animal life on physiography and soils, all combine to form a vast nexus of relationships which no type of investigation dares to disregard. The problems of the desert can not be pursued without a wide view and a comprehensive attack. The realization of their unity has been impressed upon the mind of every one who has worked intensively in the arid regions.

The study of the desert and the study of the sea have much in common in the breadth and complexity but essential unity of their problems. There are, nevertheless, some profound differences between the activating philosophy of the oceanographer and the eremologist. The attractions of marine work have recently been set forth by Dr. H. B. Bigelow in his suggestive little book "Oceanography." The morphological diversity of marine life has been its principal attraction, together with the fact that its life processes are carried on under con-

ditions which are vastly more uniform in time and space than those on land. Every reason that Bigelow has adduced for the desirability of studying the life of the ocean constitutes a tacit argument for avoiding the study of terrestrial life. Under uniform conditions of moisture none of the structures or processes are developed which adjust life to meager and uncertain supplies of water. Where uniform conditions of temperature can be secured by movements of a few fathoms per annum there can be found none of the adjustments to temperature extremes which are so important in terrestrial organisms. Many marine animals can be had in great abundance for experimental work and reared successfully under controlled conditions, whereas numerous land animals can be secured in definite stages of development only on the rarest occasions, and can be reared with the greatest difficulty. These facts merely spell our ignorance of the conditions which make the multiplication of organisms more difficult and precarious on land than in the sea. In brief, almost every one of Bigelow's examples of the desirability of marine life for scientific investigation, in behalf of effectiveness, is an eloquent argument for making the study of biology as narrow as possible, since in every case its suitability is founded on the opportunity to escape complicated situations. These complications are precisely the things that make terrestrial life what it is.

The largest problems of the desert, in every field, are those of origin and process. This applies to the origin of the land forms and mountain masses and to their determination of the character of the climate. It applies to the processes by which the face of the earth is worked over and remade under the influences of an arid climate. It applies to the origin of soils and to the slow physical, chemical and biological processes by which their development is accomplished. It applies with particular force to the great problems in the origin of plant and animal life and to the processes which make the activities of the desert organism distinctive. To the biologist the essential problem of the desert is the study of life under extreme physical conditions, of the events by which the biota of the desert have entered it, the developments by which their entry was accompanied, and the structural and functional features by which they are able to maintain themselves in it.

There can be no question as to the fruitfulness of the investigation of the biological phenomena which take place under extreme conditions. Furthermore, it is notably true of the desert that its problems are sharply defined, by reason of the vigor of the environment and the simplicity of the flora and fauna. The broadened conceptions and better balanced views that are contributed to biology by the study of desert origins and processes are an important part of the progress of science. The fact that one fourth of the earth's land surface and nearly one fourth of the area of continental United States is arid or semi-arid gives added weight to the importance of a deeper knowledge of these great areas.

RACING CAPACITY IN THE THOROUGHBRED HORSE

By Dr. HARRY H. LAUGHLIN

CARNEGIE INSTITUTION OF WASHINGTON, COLD SPRING HARBOR, NEW YORK

PART I. THE MEASURE OF RACING CAPACITY

The Solution of the Specific Problems Involved in the Invention of a Mathematical Yard-stick for Racing Capacity

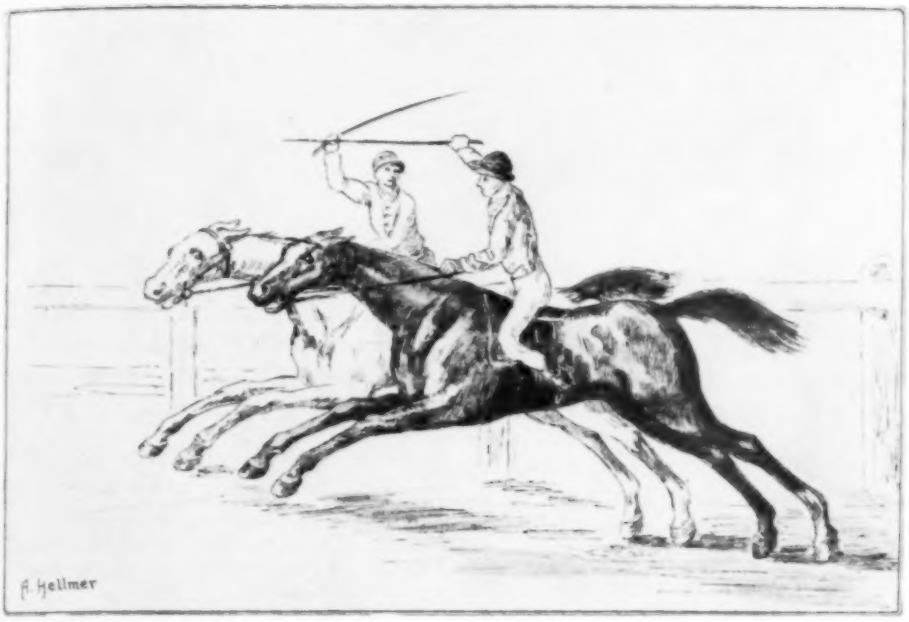
The purpose of the research reported in these two papers is to find the laws by which Nature governs the transmission of inborn racing capacity from one generation of Thoroughbred horses to another. These investigations, which began in 1923, were made possible by the support of Walter J. Salmon, Esq., distinguished breeder of the Thoroughbred horse, and by the scientific direction of the Carnegie Institution of Washington. Mr. Salmon's extensive breeding farm, Mereworth Stud, at Lexington, Kentucky, has been the field experiment station for this work; while the laboratory researches have been conducted by the Carnegie Institution of Washington in its Department of Genetics at Cold Spring Harbor, Long Island, New York.

In the Salmon library at Cold Spring Harbor there has been built up "a very substantial body of working data" for research in the genetics of the Thoroughbred horse. This library has assembled the principal racing and breeding records of all countries, and the most important books and papers by investigators and breeders of the Thoroughbred horse, published during the last 200 years, principally in England, America, France and Germany.

The laboratory has systematized carefully the first-hand breeding and racing records of some 10,000 Thoroughbred horses, about one half fillies and one half colts and geldings, mostly in the United States, England and France with a few hundred scattered in other countries. These records were organized primarily for analysis to attack the main problem, that is, as above stated, to discover the mathematical rules by which Nature transmits racing capacity from one generation of Thoroughbred horses to another.

Before we can successfully attack the genetics of any quality we must understand its essential nature as a structural or physiological entity, whichever it may be, in the individual. The quality must be defined exactly so that throughout the studies we will be measuring and analyzing and talking about the same thing. By definition "racing capacity in the Thoroughbred horse is that physiological entity which enables the horse in running races to carry great weights, for long distances, at high speed—sex and age being duly considered and other factors being constant." The thing is racing capacity—the inborn ability as distinguished from ability added to or subtracted from inborn quality by training or by other environmental influences. Racing capacity thus depends basically upon heredity. In the measure of inborn racing capacity differential environmental influence must, of course, be reduced to a minimum; but at least all influencing conditions, whether inborn or environmental, except the one being measured must be kept as constant as possible for the particular investigation.

In possession of a satisfactory definition of racing capacity, it is next necessary to examine this quality critically,



MATCH BETWEEN GIMCRACK AND BAY MALTON, 1769

FROM CONTEMPORARY PAINTING BY BEST.

The above painting shows the contemporary Thoroughbred idealized in both conformation and action. It shows also the size of jockey and the style of riding in running races in fashion prior to a generation ago when Tod Sloan introduced the now universal and faster "monkey seat" shown in Figure 3, and in the picture of Display ridden by jockey Maiben.

The Thoroughbred, or running horse, was developed in Great Britain from "Arabian, Turk and Barb" stallions, and light native British mares, during the last three centuries. While beginning shortly after the destruction of the Spanish Armada in 1588, there were a few random importations, it was really during the reign of Charles II, 1660–1685, that the importation of superior desert-bred saddle stallions laid the foundation for the Thoroughbred horse. Many centuries of severe selection had developed, in the desert countries of the Mohammedan world, a saddle horse *par excellence* in transportation, in herding, and in war. These desert stallions were brought to Great Britain and crossed with the racing type of native British mare, and thus the Thoroughbred or running horse had its origin.

To name the greatest of these imported foundation stallions, we must list the Beyerley Turk 1689, the Godolphin Barb 1730, and the Darley Arabian 1710. Each gave rise to a famous line, the descendants of which have long since been inter-crossed. The Darley Arabian was the great-great-grandsire of Eclipse (foaled during the eclipse of 1764). As a race horse Eclipse was unbeaten, and he is also the most important foundation sire of Thoroughbreds. He himself sired 334 winners of races.

For many generations the desert-bred Arabian horse was admitted without further credentials to the Thoroughbred stud-book. But now even such entry is closed, and no horse may be registered as a Thoroughbred unless both his sire and dam are also registered in the Thoroughbred stud-book.

From Great Britain the Thoroughbred has spread over the entire world, and in turn has contributed foundation stock to nearly all of the best breeds of the world's horses which require speed and stamina. About 15,000 Thoroughbred foals are now produced the world over each year. The United States, Great Britain, France, Argentina, Australia and Germany lead in the number of foals produced annually by this breed, but nearly all countries are represented to some extent. In racing capacity Great Britain probably still produces the best foals, but the United States is rapidly overtaking her.

particularly in its anatomical, physiological and developmental aspects. We must be able "to diagnose" it when we find it in an individual, but above all we must be able to measure this thing—the inborn physiological entity called racing capacity—with considerable accuracy.

The Yard-Stick for Racing Capacity

The elementary things in racing capacity are sex, age, weight-carried on the back, distance-run and speed attained. For the measure of racing capacity it is obvious that no existing yard-stick will suffice. It is necessary then to invent a new standard measure. This task can be attacked hopefully because most of the basic measures which enter into racing capacity have long ago been perfected.

The successful yard-stick for racing capacity as a physiological entity must enable one to answer the question, "Just how good a horse was 'Sir James,' judged solely by his racing performance?" It is obvious that the perfected yard-stick must measure racing capacity as shown by actual performance in each different race; that is, it must measure quality of performance on a definite mathematical scale.

Yard-sticks for distance, for weight, for age and for speed have, through the centuries, been finally perfected so that now they are very exact. Each, with its minute subdivisions, has been in use for a long time as one of the essential tools in commercial transactions, in biology and in physics. For measuring age we have the measuring stick of the year, which is quite accurate; for weight-carried on the back of the running horse we have the measure in pounds; for distance-run we have the exact measure in furlongs; for speed attained we have the very accurate yard-stick of minutes and seconds. The new measure now needed must provide the correct inter-compensation for sex, age, weight-carried, distance-run and speed attained in races truly run on good or fast tracks, all other factors being constant.

One sees immediately the practical nature of the problem. Increased weight-carried on the back and increased distance-run, each, slows down the horse; then, "How many pounds are equivalent to one furlong in slowing down the horse?" It is clear that this inter-compensation depends upon all other essential measured factors—age, sex, the magnitude of distance and the magnitude of weight with which we are dealing.

The correct formula for the measure of racing capacity must provide this inter-compensation. Each actual race which the horse runs must be measured by a definite figure called the Quality of Performance. Such a figure is a piece of evidence concerning the racing capacity of the horse. All such pieces of evidence must be properly coördinated and correctly stressed in order to determine just how good a race-horse the particular individual is; that is, what his Biological Handicap is.

The thing which these studies are trying to measure is, then, the inherent racing capacity of horse-flesh, which, under a given set of conditions of sex, age, weight, distance and speed, can be reduced to a definite figure. It is not sufficient to depend upon adjectives such as "very poor," "poor," "medium," "fine" and "superior." Definite mathematical yard-sticks in studies of this sort must supplant adjectives.

Major Factors

What does each of these several major factors, all other factors being equal, do to speed? It is necessary to go about this inquiry systematically.

1. Distance Run: In this particular phase of the main problem, it is necessary to take the best records which

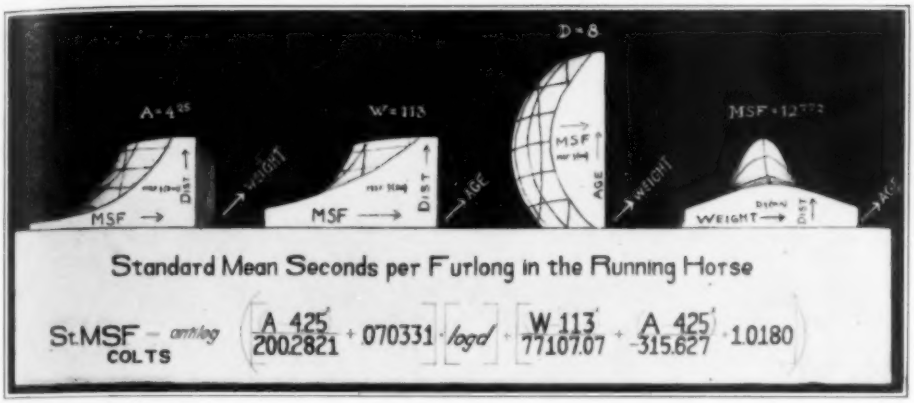

A=4.25
W=113
D=8
MSF=12.722
MSF
DIST
WEIGHT
AGE
Standard Mean Seconds per Furlong in the Running Horse
St.MSF COLTS = antilog [A 425 / 2002821 + 070331 log d + W 113 / 77107.07 + A 425 / -315.627 1.0180]

FIG. 1. BASIC FORMULA FOR THE MEASURE OF RACING CAPACITY IN THE THOROUGHBRED HORSE

ST.M.S.F. FOR COLTS: THE FORMULA AND ITS CONSTITUENT MATHEMATICAL MODELS.

In this formula there are four variables, namely, St.M.S.F., or time; A, or age in years; d, or distance-run in furlongs, and W, or weight-carried on the back, in pounds. For model-making of this sort one dimension is needed for each variable factor. Because we have only three dimensions available for model-making, one mathematical model will not suffice for the whole present formula with its four variables. Instead of one model for the whole formula, we must therefore build four types of models as pictured; and an indefinitely large series would be necessary to represent the whole range of the fourth variable for each of the four model-types.

The first model pictured makes age constant at 4.25 years, and makes mean-seconds-per-furlong for speed, furlongs for distance, and pounds-on-the-back for weight, the other three dimensions. Similarly, for model two derived from this same formula, we make weight constant at 113 pounds, and therefore have the whole range of variability for each of the other three factors. In the third model, distance-run is made constant at 8 furlongs, with the other three factors variable. In the fourth model speed, or rather its correlative, time-consumed, is made constant at 12.722 mean-seconds-per-furlong, while the other three factors are given their whole range of variability.

Thus we appreciate what adding one extra factor or dimension does to complicate curve-plotting and model-making, but also how much extension and flexibility it gives to usefulness of the formula.

Practically this formula is worked out only once for each combination of A, d, and W, and the results, in terms of St.M.S.F., are entered into permanent handy reference tables. These tables are used as follows: We have, for example, in the American Oaks, run at Belmont Park in June, 1930, for a stake of $19,600, the winning filly Snowflake, 3.25 years old, who, carrying 121 pounds, ran this truly-run 11-furlong race, with 9 horses starting, on a fast track, in 2 minutes 18⅘ seconds, or in 12.582 mean-seconds-per-furlong. Now by referring to the tables which give the values of the above formula, we locate the set-up of sex, age, weight-carried, distance-run, and speed, as above stated. We thus find the standard (or the mathematically smoothed best speed of the breed) for the particular set-up to be St.M.S.F. = 12.630. Thus, dividing 12.630 by 12.582, we conclude that the quality of performance of the filly Snowflake in this particular race was 1.0038. Thus each actual race becomes a piece of evidence for computing racing capacity in the individual horse.

Consider further (Fig. 3) the Futurity. We find that Bubbling Over, second in the race and carrying 122 pounds, is credited with the top Q.P. of .9675, while the winner, with 117 pounds, is credited with a Q.P. of .9649. In sex-adjustment, again in the Futurity, note that the filly Edith Cavell, carrying 116 pounds and consuming 102.3 seconds in running the mile, is credited with a Q.P. of .9597, while Dress Parade, a colt carrying 119 pounds, consumed .3 of a second less in running the mile, but is credited with a Q.P. of only .9544. This illustrates the adjustment of the sex-difference by the standards required for colts and fillies. Geldings have still a third standard.

American Thoroughbred horse-flesh have made for each distance; but there are a great many sets of conditioning factors. Thus the relation between speed and distance had to be plotted for each possible different combination of sex, age and weight-carried—all other factors such as track-condition and the trueness of the running being equal. The analysis of many hundreds of records shows that if we increase the distance-run, we slow down the average speed per furlong very rapidly at first, but, in the longer distances, for instance between 12 and 16 furlongs, an increased distance of a furlong or so still slows down the horse, but the amount slowed down for each furlong added decreases rapidly. It is within the range of actual racing—3½ to 12 furlongs—where added distance counts most heavily. Races naturally fall into the classes of sprints and distance races. In a sprint, there must be no conservation of energy, but the highest possible speed must be maintained from start to finish. Depending on the horse, a sprint ranges from approximately 2 to 7 furlongs. But, for a longer race, the highest average speed is attained by conserving energy, that is, by "rating the horse along" in the earlier stages of the race, then, in the later stages, urging him forward so that when the race is finished the horse is "ridden out," and he has maintained a practically uniform speed throughout the course.

A. E. Kennelly long ago proved this latter principle true in all athletic record-making, whether by man swimming or running, or by the horse trotting, or in any other speed-contest by animals. Relative uniformity of speed throughout the race is an essential characteristic of each endurance speed-contest of whatsoever kind which establishes a record.

2. Weight Carried: In weight-carrying capacity a similar set of individual studies had to be made. It was necessary to determine what weight-carried does to speed, for each condition—complex of sex, age and distance-run—all other factors being constant. These studies in weight-carrying capacity have discovered an interesting phenomenon. Let us call it the "switch-back effect." We all agree that if you put great weight on a horse it will slow him down. It is also assumed that the more weight you can take off a horse's back the faster you can make him run. But the analysis shows that there is a limit to this increase of speed by taking weight off. Whether it is because small jockeys are poorer riders on the average, or whether the horse needs a ballast, is not important here, but the fact is undoubted in the analysis of racing records. In engineering and in physiology we find many parallels to the "limits of a good thing." The kick of the gastrocnemius muscle of the frog in lifting a weight under electric stimulation, and, in artillery practise, the relation between the weight of the powder-charge and the distance which a shell of the same weight will go, are examples of "the limit of increasing and the beginning of decreasing effect by increasing cause."

3. Age: Here again it is necessary to plot many curves, each showing the best speed-records which American Thoroughbreds have made for each age. Each curve is based upon its own complex of sex, distance-run and weight-carried. Judged by every factor except age, fillies improve in absolute capacity until about 2½ years old, then gradually old age sets in and absolute capacity declines. Colts improve up to 3½ to 4½ years old, then decline; while, as a rule, geldings improve until they are about 5½ years old, then decline slowly due to old age. While most Thoroughbreds are foaled in early spring, all ages of the Thoroughbred are judged from the previous January first. Thus, in the northern temperate zone, it is seasons rather than the exact number of months and

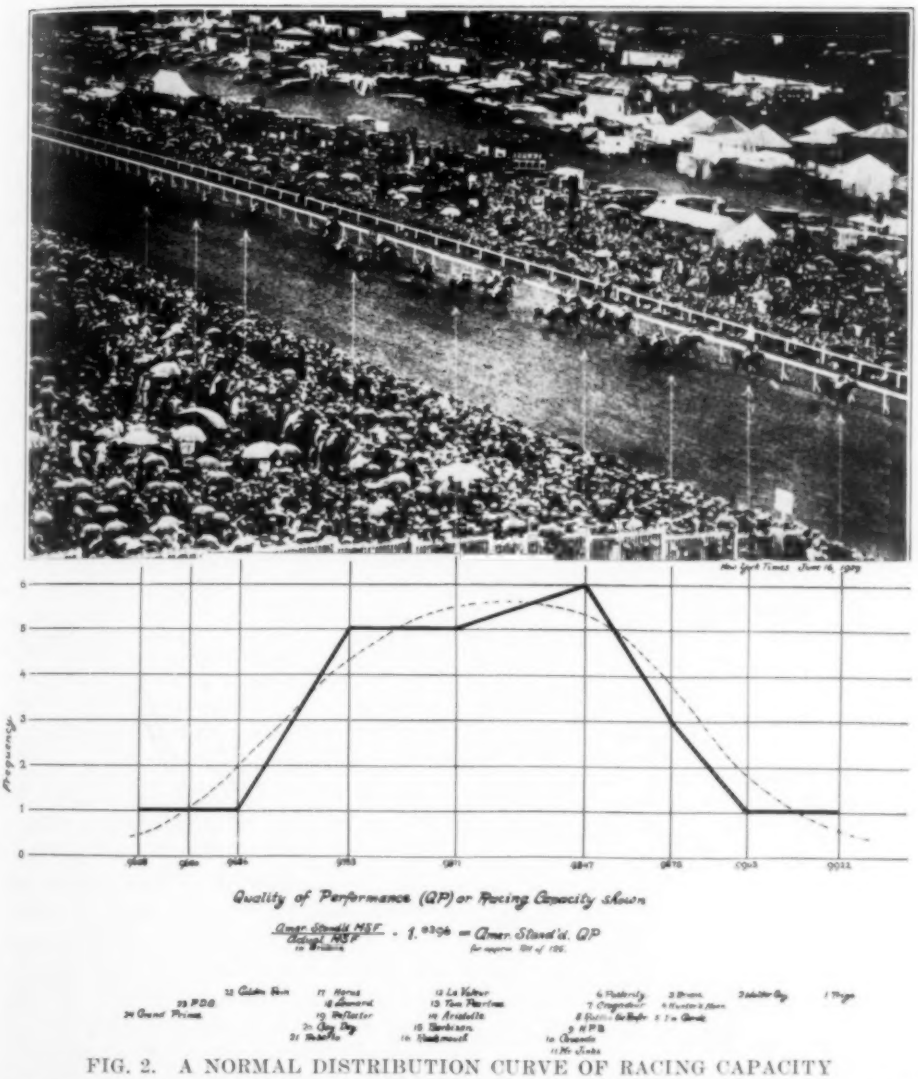


FIG. 2. A NORMAL DISTRIBUTION CURVE OF RACING CAPACITY

SHOWING THE FIELD OF 24 HORSES "NEARING THE LINE" IN THE DERBY STAKES AT EPSOM DOWNS, JUNE 5, 1929. DISTANCE: 12 FURLONGS; AGE: 3 YEARS; SEX: COLTS; WEIGHT CARRIED: 126 LBS. FILLIES ARE ELIGIBLE, BUT NONE STARTED IN 1929.

In such a set-up the starters are not expected to come out even at the finish, but, by frequency and racing-capacity, to be distributed along a normal probability curve. This picture shows the outcome of test-performances in a very complex physiological activity with almost the mathematical accuracy expected in a series of experiments in physics. With this set-up it is expected that one outstanding horse will lead; then will follow a few competitors for place; then, in the middle there will be found the great mass of entrants; then a little farther back the group will thin out, and finally will be closed by one or two trailers.

days which count most in maturing and aging the running horse.

The "switch-back effect" which was observed in weight-carrying capacity is also apparent in age. Horses improve in absolute racing ability until a certain age, then decline. Thus there must be two ages for a given racing ability in the same horse; once on the uphill of age and once on the downhill. To illustrate this principle in reference to age, it is noted that, for example, when the weight-carried is about 113 pounds, the distance-run is a sprint of about 3½ furlongs, the sex under consideration being colts, the age-range being that of practical racing and all other factors being equal, the "generally declining" older horse can, at one definite age, run as fast as he could at another definite age in his "generally improving" ability as a young horse. This seems paradoxical, but it is true.

4. Sex: Sex is, of course, a major element in racing capacity. Since sex-difference can not be measured as such by figures on a yard-stick, it is necessary to invent racing-capacity yard-sticks independently for colts, for fillies and for geldings. If racing differences in the sexes were measurable by a yard-stick, we could add the sex-factor mathematically to the formula, and thus have one formula instead of three for the yard-stick for racing capacity. But until the physiologists learn how to make such a yard-stick for sex we must continue to use the three formulae.

However, the difficulty is gotten around practically by designing the measuring stick for racing capacity for each sex as a standard ratio. In each case this standard is the "mathematically smoothed best," that is, the highest speed which "Thoroughbred horse-flesh" has thus far achieved for the particular complex of major factors, and the quality of performance of the particular horse in a race under the particular set of conditions is the ratio of the standard time for the breed to the time actually made by the individual. Thus racing capacity is made mathematically comparable in different individual horses regardless of sex, or rather with sex duly considered.

Other Factors: Others factors enter. Having learned essentially how these different major elements of sex, age, weight and distance inter-compensate each other in relation to speed, it is possible to apply the resulting formula to determine the Quality of Performance in an absolute figure for any race-performance of an individual horse truly run on a good or fast track.

In the running horse the "riding sense" or ability of the jockey comes in as a major factor. This is one additional reason why, in computing racing capacity, it is necessary to select the horse's best races. Many things can cause a horse to run slower than capacity, but nothing can make him exceed capacity.

For the time being studies will be confined to American dirt tracks, some a little faster than others. The track factor in America is simpler than that in Europe. It is true that American tracks differ in fastness, but they are all dirt rather than turf tracks, and in general the American dirt tracks are about three per cent. faster than the turf tracks of Europe. The present studies are thus confined to American dirt tracks in good or fast condition. Records of track condition are, of course, kept, whether "fast, sloppy, heavy" or the like, for the purpose later of analyzing mud-running capacities in mathematical fashion. But mud-running is not yet inter-compensated by a mathematical yard-stick, although the possibility of such inter-compensation is promising.

Inter-compensation of Factors

With an eye single to finding the correct formula for Quality of Performance these curves are systematized by fami-

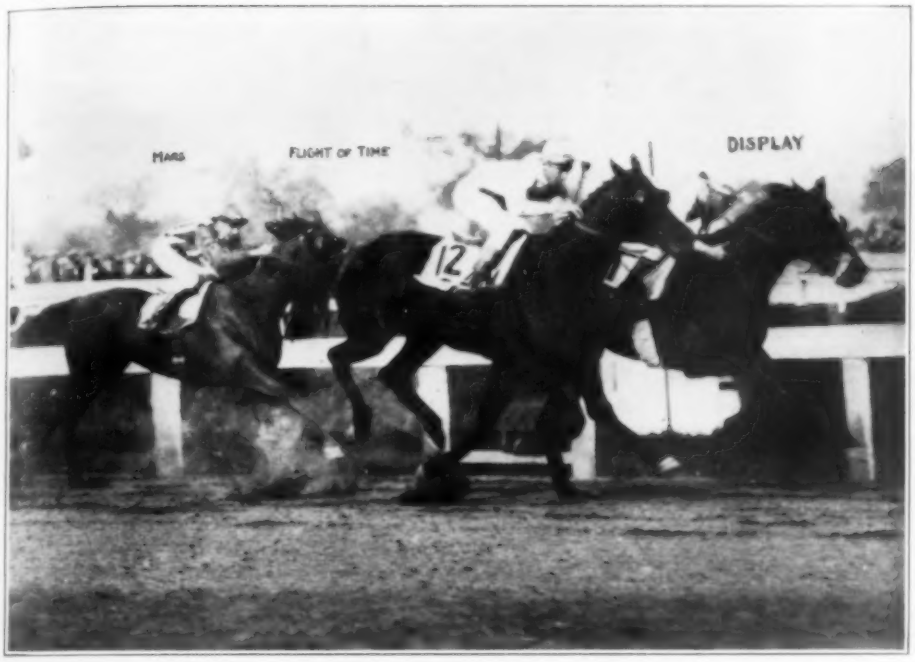


FIG. 3. AN AMERICAN HANDICAP RACE

ADMITTING BOTH COLTS AND FILLIES AND ASSIGNING EACH STARTER A WEIGHT-TO-BE-CARRIED DESIGNED TO EQUALIZE CHANCE-TO-WIN.

PIMLICO FUTURITY, November 6, 1925, Purse, $40,000. For Two-year-olds. Distance: 8 furlongs; Track condition: fast. At the finish the order was:

Place	Name	Sex	Weight Pounds	Time in Seconds	Quality of Performance
1.	CANTER	Colt	117	100.8	.9649
2.	BUBBLING OVER	"	122	100.8+	.9675
3.	DISPLAY	"	119	101.1	.9629
4.	PENSTICK	"	119	101.3	.9610
5.	CRUSADER	"	117	101.4	.9589
6.	ESPINO	"	119	101.6	.9582
7.	MARS	"	119	101.8	.9563
8.	DRESS PARADE	"	119	102.0	.9544
9.	EDITH CAVELL	Filly	116	102.3	.9597
10.	ACROSTIC	Colt	119	102.4	.9507
11.	LANCASTER	"	117	103.2	.9425
12.	FLIGHT OF TIME	"	119	103.4	.9414
13.	MARYGRACE	Filly	119	105.0	.9365
14.	PRINCE OF WALES	Colt	119	105.2	.9254

Unlike the Derby (Fig. 2) the Pimlico Futurity (Fig. 3) is a handicap race; that is, in the Futurity each entrant is assigned a certain weight-to-be-carried in pounds, which, in the judgment of the handicapper, will give the particular horse an even chance-to-win. This picture shows the leading three, not at the finish of this 8-furlong race, but at about that point where "distance begins to tell." Those horses in better condition for the particular race, and possessing better inborn distance-going capacity, show their respective merits from this point on. It is noted that the best quality of performance was not made by Canter, the winner of this race, but by Bubbling Over, who lost the race of one mile "by a nose"—too small a fraction of a second for any hand-operated stop watch to detect; but that Bubbling Over carried five pounds more than the winner.

lies; they are cross-sectioned with a minimum of "strait jacketing" to iron out their discrepancies. We have thus a set of standards for any complex of sex, age, weight-carried and distance. These standards state the "smoothed best" which the breed has accomplished up to the present time. How good a particular race-performance is, or how good a race-horse a particular individual is, depends upon its actual performance when we consider sex, age, weight-carried and distance-run, compared with the best which the breed has done under the same complex of conditions.

For colts these basic factors—age, weight-carried, and distance-run—are shown by the mathematical models (Fig. 1). These models represent both a smoothing of the actual record-making data and a plotting of the formula which these data gave. Each model shows the best "par value" which horse-flesh has achieved up to the present time under the given set of conditions. Of course the smoothed records up to any date other than the present would have been theoretically possible, but the records are now exceedingly numerous and exact, and the present proved to be a very appropriate time for standard-making. These present standards may be used no matter how much advance in racing capacity or how much degeneration may take place in the future. The standards represent a par value, and we can measure both above and below them.

After all mathematical cross-sectionings and smoothings are finished, the general formula (Fig. 1) was again applied to the basic data, and exceptionally close-fitting curves were found. This supplied the common sense—it gave confidence that the general formula for Quality of Performance is correct. In building the mathematical models for quality of performance it is necessary to use four sets or families of models for each sex instead of one single model, because there are four major factors, distance-run, weight-carried, age and speed, and nature supplies only three dimensions for mathematical models of the sort here needed. Consequently, to show all types of inter-compensation of these four elements requires four mathematical models taking three dimensions at a time. There are, of course, in Nature, as many "dimensions" as there are factors in a formula of this sort. Mathematically, in this formula there are four dimensions. We can get the surface for any one of the four mathematical models by substituting in the formula a definite value for the one missing factor or dimension. For instance, Model 1 (Fig. 1) gives all the curves of the standard mean seconds per furlong for all conditions except age, consequently a similar form like this one must be built for every age of the racing horse. Model 2 gives all standards except for weight, consequently a form similar to this one must be built for each weight. Model 3 gives all standards except for distance, consequently a surface of this sort must be found for every distance for which we may desire a standard. Model 4 inter-compensates distance, weight and age for a definite speed, namely, 12.722 mean seconds per furlong; consequently a family of forms like this one—one for each speed in which we are interested—must be worked out.

At this point attention should be called to the fact that while two horses may have the same final rating in racing capacity, one horse may be a splendid weight-carrier but a poor distance-running horse, another may pile up capacity-credits on account of coming-to-hand especially early, or maintaining high racing capacity late in old age. Thus any combination of the basic qualities, each properly stressed or weighted, goes into the final figure for racing capacity as a whole. This opens an important side-field for the still more refined ge-

netic analysis. It is the measure and inheritance of the special capacities constituent to racing capacity as an inter-compensated whole. The most important of these highly specialized capacities are distance-going capacity, weight-carrying capacity, age capacity, and mud-running capacity. In researches on each of these we desire to keep all other factors constant. And so in almost any physiological complex there is no end of unit-making, of analysis-overlapping and of inter-compensations—both structurally and physiologically in the individual and in genetic origins.

Quality of Performance: The Mathematical Formula

The formula (Fig. 1) accomplishes all these tasks of inter-compensation. It supplies all of the standards which are needed for judging the quality of performance of any colt under any set of conditions of age, weight-carried and distance-run, other factors being constant. But, as previously stated, a set of curves and formulae—independent but of parallel type—have been worked out for each sex.

For each set of conditions the standard represents the quality of performance at par, or QP = 1.000. Thus, if a horse under a given set of conditions makes the mean seconds per furlong given in the standard for this set, his quality of performance is 1.000. If, in a truly run race on a good or fast track, his mean seconds per furlong is less than the standard, then his quality of performance is more than 1.000. If he requires more time than called for by the standard, then his quality of performance is less than 1.000.

The formula then reads as follows:

Quality of Performance

$$\text{Q.P.} = \frac{\text{Standard Mean Seconds per Furlong.}}{\text{Actual Mean Seconds per Furlong.}}$$

When we compare two excellent performances in either the same or in different races, we immediately ask: Which horse ran the better race? The thing can be argued back and forth without decision, unless we have definite standards of measurement. But with such yard-sticks we can answer it definitely, if we agree that the races were equally well ridden and truly run and that the tracks were equally fast. We know the sex and age, and it is necessary then only to determine mathematically the way "horse-flesh" inter-compensates weight-carried, distance-run and speed for the particular physiological and environmental set-up.

Another question often arises, "Why, if Man o'War was the best horse which America ever produced, did he not win all of his races?" It must be recalled that quality of performance which a horse shows in a given race is a very delicately balanced affair. In order to deliver his maximum capacity the horse must be in prime condition, he must be well ridden, the race must be truly run, and many other factors must be favorable.

Moreover, if the particular performance is made in a "handicap race," different horses carry different weights. These weights are assigned by the handicapper in a manner which he believes will give each horse, on the basis of his "past performance," an even chance to win. If such handicapping were an exact science, and the "quality of performance" of the individual horse were never variable, then all horses in the particular handicap race would cross the finishing line at the same instant. But, as a matter of fact, actual quality of performance is subject to great variability. This is an important factor which must be considered in the measure of racing capacity. Some horses show little range in quality in their successive best races; they are "reliable." Others are erratic, sometimes running very superior races, while at other times they are disappointing. It is, therefore, necessary in judg-

ing the racing capacity of the horse to take "only but all" of his best races into consideration.

It is this variability in quality of performance that makes racing so enticing as a sport, and also which makes it interesting and important to science. Both in the keen judgment of "racing men" and in sound scientific computation, the mathematical picture of a selected "horse-race" is painted with the brush of odds or probability, and not with the finger of certainty. In fact, many of the former cocksure formulae of so fundamental a science as physics are now being stated in terms of probability. Of course when we compare the subject-matter of physics with the subject-matter of biology, generally but not always, the highest class-probability predicted in a physical matter much more nearly approaches certainty than does such probability when it involves a complex biological element.

Racing Capacity or Biological Handicap: The Mathematical Formula

In order to distinguish between quality of performance which applies to the single race, and Racing Capacity which applies to the whole racing career of the horse as a measure of his "inborn racing qualities," the measure of the individual's racing capacity for his whole career is called his "biological handicap," or his "B.H." All of the actual races run by the individual horse must be taken into consideration in order to answer the question, "Just how good a racehorse was 'High Spirit'?" *i.e.*, "What was his racing capacity, that is, his biological handicap?" While every race is a piece of constituent evidence, it is found that the real capacity of the horse is better measured by taking the best of his races, in accordance with definite principles of selection. The number of races selected, as standardized by the present study, depend upon the total number run and varies from 1 to 10 as follows:

Number of races, truly run and well ridden on good or fast track, selected for determining racing capacity or B.H.:

Number run	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	20+
Take best	1	1	2	3	4	5	5	6	6	7	7	7	8	8	8	9	9	9	9	10	10

Now, if we take the mean Quality of Performance of these best races, we get a good picture of the racing capacity of the horse, particularly if he has run a large number of races. Any horse which competes in 6 or 7 races, truly run on good or fast tracks, under varying conditions of age, distance-run and weight-carried, supplies data for a good mathematical picture of his real capacity.

But men who handle horses do not use the term "par value" and "racing capacity"; they say, "This is a 110-pound horse," and "That is a 120-pound horse," not meaning, of course, that he always carries so many pounds, but that that is "how good a horse he is." It is another technical use for the word "pound," which, depending on the context, might be avoirdupois, English money, or racing capacity. Now it is found useful to transform mean quality of performance into pounds, or biological handicap, and the following formula does the task very well:

$$\text{Biological Handicap (B.H.)} = (716\ \overline{QP}) - 585.$$

Final B.H. is computed when the racing career is finished. B.H. computed at any earlier date is tentative (BH_t), and is based on performance to the particular date. It makes no difference in subsequent mathematical calculations whether this straight line transformation is used to turn mean quality of performance into biological handicap, or

ETCHED FROM AN ACTUAL PHOTOGRAPH.

DISPLAY, BAY COLT 1923, BY FAIR PLAY OUT OF CICUTA,

WINNING THE HAWTHORNE GOLD CUP, OCT. 11, 1928. DISTANCE RUN—10 FURLONGS. WEIGHT CARRIED—126 POUNDS. AGE 5.75 YEARS. RACE TRULY RUN. NINE STARTERS. FAST DIRT TRACK. TIME 2:03. THESE CONDITIONS WORK OUT MATHEMATICALLY FOR DISPLAY IN A QUALITY OF PERFORMANCE—1.0019. DISPLAY RACED IN HIS 2, 3, 4, 5 AND 6 YEAR-OLD FORMS, RUNNING 96 RACES IN ALL, OF WHICH HE WON 23 RACES AND WAS SECOND 23 TIMES. HIS RACING CAPACITY IS RATED AT 130.93. HE WAS BRED AND RACED BY WALTER J. SALMON, ESQ., IN THE COURSE OF THE EXPERIMENTS REPORTED IN THESE PAPERS.

mean quality of performance is used directly. In either case it measures quite accurately the same "inborn stuff," on the yard-stick of "horse-flesh standards for running at high speed"—sex, age, weight-carried and distance-run being duly considered.

THE PRINCIPLE OF ADDED FUNCTIONS: A USEFUL TOOL IN YARD-STICK INVENTION

Each basic research should yield a useful new tool. In constructing the formula for the standards mean seconds per furlong, the principle of added functions has been developed. Statistical analysis of problems which involve several simultaneous and interacting factors need such a tool.

When it is desired to measure, as a single entity, a complex quality composed in turn of several relatively simple elements, different methods have been tried. The method of index-making is common in the commercial world. In statistical studies multiple correlation has been developed. Each has its uses and limitations. In problems of the sort presented by the physiological nature of racing capacity the method of added functions as here developed is most useful; it has flexibility and it is thus close-fitting to the observed data.

The formula for the measure of racing

capacity is a specialized use of the principle of added functions. Its technique can be used in measuring as an entity any quality, whether a natural physical or physiological entity, a "syndrome," or an arbitrary collection of elementary units brought together through a "chain of connecting functions," provided each constituent element is, in turn, already measurable directly on its own independent basis.

In the theory of functions this work demonstrates the principle which may be stated as follows: If two things (for example, distance and weight) are each independent functions of the same third thing (for example, speed), then these first two things (distance and weight) are, for each specific value of this third thing (that is, speed) unique functions of each other. The principle of added functions, by the mathematical models shown in Fig. 1, illustrates this very fundamental principle quite clearly.

In heredity Nature seems to function through many somatically independent forces tied together in pairs by their commonness as functions each of the same third factor. This tying together, through a third element, of two apparently independent factors seems to be a basic characteristic of the working of Nature, if indeed it is not the main structure of Nature itself.

Conclusion

By means of the definite yard-stick here developed we can now, with a single figure for each, answer such questions as "Just how good a race horse was the colt Man o'War?" and "Just how good a race horse was the filly Snowflake?" We know that Man o'War was a chestnut colt, by Fair Play, out of Mahubah by Rock Sand, that he raced in his 2- and 3-year-old forms, that in all he ran 21 races carrying from 115 to 130 pounds, for distances from 5 to 13 furlongs, that he won 20 of these races and was second in the one race which he lost, that he "crossed par" 9 times, and that he established many records. We know that Snowflake was a chestnut filly, by Mad Hatter, out of Snowdrop by Cicero, that she raced in her 2-, 3- and 4-year-old forms, that she ran in all 30 races, carrying from 103 to 126 pounds, for distances ranging from 4½ to 11 furlongs, that she won 7 races, was second once, and that she "crossed par" 3 times. We also know the sex, age, weight-carried, distance-run, speed (mean seconds per furlong), track condition and "trueness of the race" for each of these individual performances. Although these two horses are of different sex, and never ran at exactly the same age, for the same distance, carrying the same weight, the new yard-stick for measuring the inborn racing capacity of the Thoroughbred horse rates, on the same scale, Man o'War at 139.25 and Snowflake at 127.31.

If we were studying a quality like stature in man this preliminary invention of the yard-stick would be unnecessary, because the foot-rule and the meter-stick have long since been standardized. In mathematical genetics, the study of variable qualities, whether structural or functional, demands first of all a good yard-stick, even if it has to be developed or invented for the specific purpose. The two conditions necessary for genetical analysis of the type herein reported are, first, measurableness of the subject-quality in the individual—with the yard-stick in hand, and second, some indication that the particular quality thus measured tends in some manner to "run-in-the-family."

We are now in possession of a reliable yard-stick for the measure of racing capacity in the Thoroughbred horse. We are, therefore, now ready for the next stage of these researches which will seek the mathematical rules by which nature governs the inheritance of racing capacity.

(To be concluded)

THE CONQUEST OF MALARIA: ITS NATURE AND SOCIAL SIGNIFICANCE

By Dr. ARTHUR L. BEELEY

PROFESSOR OF SOCIOLOGY, UNIVERSITY OF UTAH

So vital is the rôle of disease and death in human affairs that the Gibbon of the future will, no doubt, explain the rise and fall of civilizations less in terms of political and social economy and more in terms of disease and sanitation. Such a bio-social interpretation of human history is well-nigh inescapable when we consider for a moment the number and variety of pestilences that from time immemorial have afflicted the race.

When events are viewed in this light their meaning is often quite different from that which tradition assigns them. For example, it is becoming more and more apparent that the American success at Panama was not primarily an engineering feat, great as that was, but rather a sanitary triumph over two of the oldest and most pernicious human maladies—yellow fever and malaria.

The occasion for this review of the developments that have led up to the potential—though not the actual—conquest of malaria, is the recent death of Sir Ronald Ross, whose brilliant discovery in India a generation ago added the last link to a chain of scientific knowledge by means of which it is now possible to eradicate this disease completely. The significance of this new knowledge is apparent at once when it is seen that, even to-day, malaria still exacts an annual death-toll of approximately twenty-five million persons in various parts of the world.

Past and Present Theories of Malaria

Because the symptoms of a malarial attack are so distinctive, there seems to be no difficulty in tracing the disease back as far as 1,000 B. C., according to Singer's "Short History of Medicine." Hippocrates refers to the disease and Galen describes it in some detail. Herodotus tells how the Egyptians who inhabited the marshes of the Nile were plagued with gnats, and how they wrapped themselves up in nets at night.

Some writers contend that malaria was a contributory cause of the decay of Greek and Roman civilization. But however conjectural this may be, it is a fact, nevertheless, that the mythologies of these cultures contain explicit allusions to the disease. Apollo, the sun god, for example, was worshiped, *inter alia*, for his reputed power to drive away the malaria mists. The healing rays of the sun were thought to be his arrows.

While the pre-scientific theories of malaria have now been completely exploded, the term itself, derived from the Italian *mala aria*, meaning bad air, is still used to designate that class of intermittent and remittent fevers (sometimes called ague, marsh fever, hill fever, paludism, etc.) in which the infection is spread from one person to another by means of a mosquito.

The present scientific explanation of malaria can be epitomized by saying that whenever a female mosquito of the genus Anopheles feeds on a human being with malaria parasites in his blood, the parasites thus extracted undergo development in the insect's stomach. After two or three weeks the mosquito becomes infective, and when, in this state, it bites another human being, it injects into him certain developmental forms of the parasite which are now present in its salivary glands. These minute para-

sites enter the red cells of human blood, multiply rapidly and give off a poison which produces the characteristic fever known as malaria. In a day or two this poison may be eliminated from the patient's system, in which case the fever will subside, but soon another generation of parasites comes to maturity and the patient experiences a recurrent attack. Unless properly treated with quinine these recurrent attacks tend to continue, often resulting, directly or indirectly, in death.

The successive steps which led up to this knowledge constitute an inspiring chapter in the history of human progress.

The Discovery of Quinine

The first great landmark in the conquest of malaria was the discovery of quinine in the seventeenth century.

Quinine is the most important alkaloid obtained from cinchona bark. Its chief value, says the pharmacologist, is its effectiveness as an antipyretic or fever-reducing agent. It is a specific antidote for and a general prophylactic against malaria.

The word itself contains the clue to the interesting history of this drug, for *quina* is the Peruvian word for bark. It seems to be well authenticated that this bark was officially named Cinchona Bark by Linnaeus in 1742, in honor of Countess d'El Chinchona who was chiefly responsible for its introduction into Europe. While in Peru she had been cured of an attack of malaria by the use of this tree-bark, a remedy well known to the Indians of that region. The benefits were so striking that the Countess took some of the bark back to Spain with her in 1640.

It seems not too much to say that no drug has proved a greater boon to mankind than quinine. Its extensive use throughout the world, especially during the past fifty years, has materially reduced the ravages of malaria.

Finding the Malaria Parasite in Human Blood

The use of quinine, however, gave no clue as to the cause of the disease for which it has proved to be so effective a cure. It was not, in fact, until something over two hundred years after quinine had been introduced into Europe that the immediate cause of malaria was definitely established.

With the improvement of the microscope in the nineteenth century, and the scientific study of human pathology which that instrument promoted, it was inevitable that medical men would, sooner or later, examine the body fluids —especially the blood—for clues as to the possible cause of disease. In the case of malaria, such microscopic work soon established the fact that the blood of a malaria patient contains granules of pigment, a substance then thought to be due to the chemical action of "bad air" on the red blood cells. It was not difficult to see, therefore, why Professor Alphonse Laveran, possibly stimulated by the work of his older and more illustrious contemporary, Pasteur, would try out the parasite theory in explaining malaria pigment.

From the staff of Val-de-Grâce Military School of Medicine in France, Laveran was transferred to a military hospital at Constantine, Algeria. It was here, while examining the blood of a soldier suffering from paludism (or marsh fever as the French call it), that he discovered the parasite.

Quoting from his own work, "Du Paludisme et son hématozoaire," published in 1891 (Martin's trans., 1893), we read:

> . . . as I was trying to account for the mode of formation of the pigment in the palustral blood, I was led to see that besides melaniferous leucocytes, spherical hyaline corpuscles without nucleus could be seen, and also very characteristic crescent-shaped bodies.
>
> I had proceeded thus far with my researches and was still hesitating whether these elements

PROFESSOR ALPHONSE LAVERAN
(1845–1922)

were parasites, when on November 6, 1880, on examining the pigmented spherical bodies mentioned above, I observed on the edge of several of these elements, moveable filaments or flagella whose extremely rapid and varied movements left no doubt as to their nature.

Laveran's discovery that malaria is caused by a parasite was not only the second high-water mark but, without doubt, the most important single event in the solution of the malaria problem. In recognition of its magnitude Laveran was appropriately honored by the French Academy of Sciences in 1889 and by the award of the Nobel prize for medicine in 1907.

The next baffling question was, how does the malaria parasite get into human blood?

On the Trail of the Mosquito

The scientific study of parasites had, in the meantime, been making rapid strides. One of the striking biological processes which this branch of knowledge had already made plain is the fact

that certain parasites spend part of their lives in one animal and the rest in another.

The first scientist to discover that man and the mosquito are joint hosts to a parasite was Sir Patrick Manson in 1878, when at Amoy, China, he discovered the part played by the mosquito in a disease called filariasis, a morbid condition resulting from the infection of the human body with certain worms. (It should be stated, parenthetically, that the brilliant work of Dr. Walter Reed on yellow fever and mosquitoes was not accomplished till 1899, in Cuba.)

Manson, who had become one of the leading figures in tropical medicine, later devoted himself to the malaria problem. Taking the conclusions of Laveran—elaborated by MacCallum in 1897—and reasoning from his own experience with mosquitoes, he advanced the hypothesis that the flagellum (which appears only when malarial blood gets outside the human body) is a means of facilitating the parasite's escape for the purpose of establishing a new life-cycle to be lived partly in water and partly in man.

Manson told these things enthusiastically to Major Ronald Ross, a young colleague who, in 1894, had returned to London from medical service in India, where he had been deeply impressed by the baneful influence of malaria and other tropical diseases. Having previously decided to study public health, Ross returned to India resolved to "follow the flagellum," as Manson advised, and to work out the entire problem thoroughly.

After much fruitless work, however, Ross discovered that the flagellum completely disappears soon after it enters the mosquito's stomach. He therefore abandoned Manson's hypothesis to the effect that the parasite escapes from the mosquito into water and that it later reaches the body of man by ingestion. He concluded that the parasite, in one form or another, must remain in the tissues of the mosquito until it reenters its human host.

For two years Ross worked untiringly, often under the most trying conditions. By trial and error he evolved his own technique for dissection and discovered that of the many species of mosquito only a few carry malaria. It was at Secunderabad, India, in 1897, that Ross finally found malaria parasites in the stomachs of Anopheles mosquitoes which had been bred from larva and fed upon a human case of malaria.

The dramatic details of this discovery are quoted from Ross's own "Memoirs."

> The dissection was excellent, and I went carefully through the tissues, not so familiar to me, searching every micron with the same passion and care as one would search some vast ruined palace for a little hidden treasure. Nothing. No, these new mosquitoes also were going to be a failure: there was something wrong with the theory. . . . I was tired, and what was the use? I must have examined the stomachs of a thousand mosquitoes by this time. But the angel of Fate fortunately laid his hand on my head; and I saw a clear and almost perfectly circular outline before me of about 12 microns in diameter. The outline was much too sharp, the cell too small to be an ordinary stomach-cell of a mosquito. I looked a little further. Here was another, and another exactly similar cell. The afternoon was hot and overcast; and I remember opening the diaphragm of the sub-stage condenser of the microscope to admit more light and then changing the focus. In each of these cells there was a cluster of small granules, black as jet. . . . (the malarial pigment).

All that now remained was the experimental proof of this discovery. Owing to his transfer to Calcutta where human malaria was scarce, Ross used malaria-infected birds in order to trace, step by step, the complete life-cycle of the parasite. When this task was successfully completed in 1898, he triumphantly telegraphed to Manson, who reported the news at a meeting of the British Medical Association a few weeks later.

SIR PATRICK MANSON
(1844–1922)

Ross the Man

While Ross was working alone in India a group of Italian scientists were independently confirming his results at Rome. Later on, a long and bitter controversy arose between Ross and Professor Grassi regarding credit for the discovery. In the minds of such men as Laveran, Koch and Lister, however, there seems to have been no doubt about the priority of Ross's work. Moreover, the honors which sooner or later were showered upon him leave no room for doubt as to the world's appreciation of his work. He was elected to The Royal Society in 1901; awarded the Nobel prize for medicine in 1902; knighted in 1911.

Up to the time of his death in September, 1932, at the Ross Institute for Tropical Diseases, in London, he remained bitterly critical of the medical profession, largely for their apathy in adopting his proposals for the world-wide eradication of malaria.

Although trained as a physician he

preferred the title of scientist. His mind was extremely versatile as well as keen. His many volumes of poetry and prose are said by competent critics to be of extraordinary caliber. Certain of his published studies in mathematics are also said to contain unmistakable signs of genius.

The International Scope of the Problem

The final identification of the parasite-carrier soon resulted in the inauguration of vast anti-mosquito campaigns in various parts of the world. Comprehensive systems of drainage and screening have been adopted with great success in Italy, in Africa, The Federated Malay States, in Central America and more recently in the Southern States. At Panama, for instance, during the construction of the Canal, the technique of mosquito-eradication reached a new level of perfection. General Gorgas wrote to Ross in 1914:

> If we had known no more about the sanitation of Malaria than the French did, I do not think that we could have done any better than they did. Your discovery that the mosquito transferred the malaria parasite from man to man has enabled us at Panama to hold in check this disease, and to eradicate it entirely from most points on the Isthmus where our forces were engaged.
>
> It seems to me not extreme, therefore, to say that it was your discovery of this fact that has enabled us to build the Canal at the Isthmus of Panama.

A great impetus was given to the world-wide campaign against malaria by the creation, in 1923, of the Malaria Commission of the League of Nations, a body whose primary object is to pool the experience of all nations with anti-malarial measures. In 1927, after careful study, this Commission concluded, among other things, that there is as yet no single method of eradication which can be described as superior to all others. "Malaria control is a local problem. . . . No country should follow slavishly the method used by another merely because it was successful there." The Commission also emphasized the need for a "continuous scientific study of malaria," specifically the problems of housing, medication, immunity, the biology of the Anopheles and the study of deltas.

That the practical problem of malaria is by no means solved, a careful study of the International Health Year Book, published by the League of Nations in 1930, will show. Malaria is still the great disabling and death-dealing disease of the tropics. In Ceylon, for instance, it is by far the most prevalent of all diseases. In the Philippines, in Turkey, in India, in the Malay States and in parts of Russia it ranks among the most important causes of disease and death. Even in Greece, Holland, Italy and Roumania it is still a menace to health and welfare.

No American, incidentally, can read the health reports of the League of Nations without a feeling of pride at the magnificent scope of the international health work of the Rockefeller Foundation. In 1929, for instance, in addition to its yellow-fever and hook-worm activities, it assisted eighteen foreign governments engaged in malaria campaigns, demonstrations or surveys, either by contributions to their budgets or by the loan of staff members who served as consultants.

Malaria in the United States

While malaria is no longer a serious problem in the northern states, it is, nevertheless, by reason of climate and economics, a disease of considerable importance in the South. Mortality statistics for the United States show that in 1929 there were 4,084 deaths from malaria in the registration area, or 3.5 per 100,000 of the population. Three fourths of these deaths occurred in the six Southern States listed below. It is significant, also, that the death-rate from

SIR RONALD ROSS

SHORTLY BEFORE HIS DEATH IN 1932.

malaria is generally higher in rural communities and amongst colored people.

DEATHS FROM MALARIA PER 100,000 POPULATION, SIX SOUTHERN STATES, 1929

Arkansas:	36.3	
White		29.3
Colored		56.4
Florida:	33.5	
White		26.0
Colored		51.3
Georgia:	23.5	
White		18.1
Colored		32.6
South Carolina:	22.0	
White		10.7
Colored		35.1
Mississippi:	20.4	
White		15.6
Colored		25.1
Alabama:	16.8	
White		12.3
Colored		24.8

That the presence of malaria in any community is evidence of a social and economic difficulty rather than a medical one, is a statement no one can now deny.

The effective demonstrations of the United States Public Health Service in a number of southern states proved this to be true twenty years ago. Moreover, the experiments initiated by the International Health Board in 1922 further proved that the small town or rural district can virtually rid itself of malaria at a per capita cost of from forty-five cents to one dollar per year.

Some Reflections

The conquest of malaria is a fascinating record of unmistakable progress. It is another example of man's collective victory over an insidious enemy in his natural environment; and it is heartening to consider it at a time when we are bewildered by our chronic failure to cope successfully with the social forces which also make up our environment.

It was, moreover, a triumph of means as well as of ends, for it could never have been done without the aid of the microscope and many of the other techniques known to science. Nor was it the work of a few great men. It represents, rather, the cumulative work of hundreds of obscure scientists whose specific contributions can never be identified, still less rewarded.

The story of this conquest—barely sketched here—also throws a flood of light on the incredible processes of biological evolution, especially the way in which one form of life interacts with another in the inexorable struggle for existence. It shows, too, how many of our current ideas of life in general and disease in particular are the vestiges of a pre-scientific era in which man's understanding of life phenomena was circumscribed by what he could see with his naked eye.

THE ORGANIZATION OF INCA SOCIETY

By Professor GEORGE PETER MURDOCK

YALE UNIVERSITY

THE communalism of primitive tribes has long been clearly distinguished by social scientists from socialism in advanced societies. Instances of the former are legion. Soviet Russia, the classic example of the latter, is not, however, the first but the second experiment of a great civilization with socialism. The first came to an end four centuries ago with Pizarro's conquest of Peru. In the last few years the researches of Baudin in France and Trimborn in Germany have revolutionized our knowledge of Inca society, and a review of the facts now known may prove illuminating and suggestive.

Only an acquaintance with the geographic environment can give an adequate conception of the magnitude of the achievement by which the Inca dynasty welded into a political and cultural unit ten million Indians of diverse tribes in a territory extending 2,500 miles from central Chile northward to the border of Colombia.

The Andes parallel the Pacific coast in two majestic ranges, the Eastern and the Maritime Cordilleras, forming a gigantic avenue lined with snow-capped volcanoes. The prevailing trade winds from the South Atlantic lose most of their moisture in the Amazonian jungle and on the forested eastern slope of the Eastern Cordillera. Enough reaches the inter-Andean plateau to produce a very moderate rainfall, but the winds are completely parched when they descend the Maritime Cordillera to the coast. The Pacific contributes fog but no rain. Consequently the narrow coastal zone is, except in the far north, a desert of windblown sand with no vegetation save a few cacti and fugitive plants. The monotony of this barren coastal strip is broken, at intervals of about thirty miles on the average, by bands of green—ribbons of vegetation which mark the courses of short, and often intermittent rivers fed by the melting snows of the Maritime Cordillera. Only in the fertile but isolated valleys of the permanent streams is man able to live and thrive.

Between the two ranges of the Andes lies a plateau 12,000 feet in average elevation and from 100 to 200 miles in breadth. It is broken up, however, into large *hoyas* or drainage basins by numerous transverse ridges and ramifying spurs. A series of rivers, shallow, clear and swift, drain the several basins, pass to the east through mighty gateways or *pongos* in the Eastern Cordillera and plunge to the swampy lowlands to join the sluggish Amazon. The countless snow-clad peaks ranging from 18,000 to 23,000 feet in altitude, the wild labyrinthine gorges, the valleys sometimes a mile in depth and inaccessible from above, the land riven by earthquakes and seared by lava flows, all conspire to produce scenery of breathless grandeur. Although rich in mineral resources, the country supports only a meager mammalian fauna. The temperature varies little in any season from the annual mean of 50° F., but its range at different altitudes and at different hours of the day may be immense. The plateau is treeless except for occasional clumps of gnarled evergreens and for thickets of reeds along the streams. Grass-covered slopes alternate with rocky wastes, swampy moors and stretches of desert. The scanty vegetation never succeeds in moderating the

monotonous gray of the landscape. "It is never winter here, never spring, never summer; it is a land of eternal autumn."

Lacking in navigable rivers, poor in fauna and flora, surrounded by desert and jungle, its few habitable regions isolated from one another by barren wastes and almost insurmountable mountain barriers—an environment theoretically more unfavorable for the growth of civilization could scarcely be imagined. Yet civilization did develop here, stimulated by migrations and by cultural diffusion from Central America. By the beginning of our era, regional specialization had produced distinctive elaborations of the common cultural heritage in three widely separated parts of the area: the Chimu civilization on the northern coast of Peru, the Nazca culture in southern Peru, and the Tiahuanaco civilization in the Bolivian highlands. Between 500 and 600 A. D. the Tiahuanaco culture was spread, apparently by conquest, throughout the plateau and the coast. After three centuries of dominance, however, it suddenly collapsed through some unknown cataclysm and was succeeded by a period of disorder.

The Incas, though their origin is shrouded in myth, seem to have been one of the many small warring tribes which maintained a precarious economic and political existence in the highlands. Their chieftain and first historical ruler, Sinchi Rocca, about the year 1100, established hegemony over a group of tribes inhabiting one of the mountain valleys tributary to the Urubamba River. His successors, by a brilliant succession of conquests, established the Inca empire, which reached its maximum extent under the tenth ruler, Huayna Capac (c. 1485–1525).

Life in Peru from time immemorial had centered in the *ayllu*, an exogamous clan united by common descent, usually in the female line, by the cult of a common totemic ancestor, and by the duty of avenging injuries to its members. Each clan laid claim to a definite territory and inhabited a single village of perhaps a hundred irregularly clustered huts of stone, mud or adobe.

The house, its furniture and an adjacent garden plot belonged to the individual family. The clan owned collectively, however, all land outside the village. Its members enjoyed equal rights to game, wood and pasturage on the communal forest and meadow, and they tilled in common a portion of the agricultural land for the support of the chief, the cult and the aged. The major portion of the cultivated land, however, was not communally tilled but was periodically distributed among the individual families to exploit for their own profit and at their own risk.

Maize or Indian corn and the misnamed "Irish" potato constituted in most regions the mainstay of existence, supplemented by lima and kidney beans, squash, sweet potatoes, tomatoes, chili peppers, and other vegetables. The flesh of the domesticated dog and guinea-pig, fish, game birds, and an occasional deer served to relieve but slightly the predominantly vegetarian fare of the Peruvians.

The llama and alpaca, the only large animals ever domesticated by an American Indian tribe, formed the basis of economic life in the regions too high or too arid for productive agriculture. They were too valuable as beasts of burden and for the wool they provided to be used very often for food. They grazed on the grassy uplands in large herds, each the communal property of a clan, and were driven once a year to the village to be shorn. The wool, which was equally distributed among the several households, together with cotton imported from the coast, was spun into thread by the women and woven on looms into the fabrics from which the

poncho-like garments of both sexes were made.

Food, shelter and clothing, in spite of certain regional differences, varied little within any particular clan. The chief alone towered above the common level of the clansmen, from whom he was distinguished by a higher standard of living, exemption from labor in the fields and the possession of private estates and herds. He held his position by various rules of succession, and his power ran the gamut from purely personal influence to military despotism. Clans, though sometimes politically autonomous, often united into larger groups or tribes on the basis of common descent, the need of mutual protection or the necessity of joint action in the regulation of irrigation. In such cases the leader of one clan became the tribal chief while the others constituted a tribal council. In a like manner tribes were sometimes further compounded into confederacies and even into feudal states.

The Inca empire followed this typical evolution from clan to state. It went, however, a long step farther. The eighth ruler, Pachacutec (c. 1400–1448), transformed the irregularly organized feudal state, which he inherited, into a symmetrical hierarchy of groups and officials pyramided strictly according to a decimal system, and he initiated therewith a regulated system of production, distribution and consumption which bore most of the earmarks of what we have come to know as state socialism. And he accomplished this feat of statecraft with a minimum of violence to existing institutions.

The clan, the most vital institution in Peruvian life, was not destroyed. On the contrary, it was absorbed, virtually intact, into the imperial system, and became, indeed, the very cornerstone of that system. It was merely standardized. The Incas classified all males into ten age-grades on the basis, principally, of their capacity to work. The system took into account only the eighth of these, the so-called *purics*, men in the prime of life, between twenty-five and fifty years of age. Each *puric* was a married man, a householder and a laborer for the state as well as for himself. The clan, as standardized, comprised exactly one hundred *purics* and hence received the name of "century." The former clan chief, instead of being deposed, was allowed to remain in office; he was absorbed into the official hierarchy as a "centurion." The century likewise retained the old clan lands. Its new artificial character even invested the latter with a new significance; common territory tended to supplant community of blood as the primary bond of association.

The century was subdivided into ten "decuries" of ten *purics* each, of whom one was appointed "decurion" or foreman over the rest. Similarly ten centuries were grouped into a "phratry," and ten phratries into a "tribe," which therefore numbered 10,000 *purics*. The tribe and phratry corresponded to the earlier political confederations, and the former chiefs and petty kings usually remained in office although sometimes subject to the advice and control of resident Inca delegates. Four tribes formed a "province," over each of which presided a "governor" with highly important civil, judicial and military functions. The provinces of the empire were in turn grouped into four "quarters," each ruled by a "viceroy." These powerful officials resided at court and formed a sort of imperial council which advised the monarch and probably exercised a certain measure of limitation on his power.

In this administrative pyramid a steady stream of reports flowed up-

ward "through official channels," and a stream of orders flowed downward; there was no contact between functionaries of equal rank. A corps of secret agents, quite outside the hierarchy, circulated incognito through every corner of the empire to observe conditions, hear complaints and spy upon officials.

At the apex of the pyramid stood the divine ruler, the Sapa Inca himself, directing the operations of the vast administrative machine with an authority not far from absolute. His subjects revered him as a god on earth, the son of the Sun, and approached his person only with uncovered feet and a symbolic burden on the shoulders. He wore clothing of the finest wool, dined only from vessels of gold and silver and never used the same garment or utensil a second time. Although provided with numerous concubines, he had but one legitimate wife, the Coya, who, at least in later times, was necessarily his own eldest sister. The first son of this union, if sufficiently capable, succeeded to the throne. One result of such a brother-sister marriage was that the monarch's son was at the same time his nephew. This arrangement possessed manifest advantages in an empire where the patrilineal rule of succession prevailed in some regions and the matrilineal or uncle-nephew principle in others. The long line of Inca emperors reveals only one man of mediocre talents; all the rest displayed exceptional energy, resourcefulness, tolerance and magnanimity in the conduct of affairs. No dynasty with a higher average order of capacity has graced a throne in the whole of human history.

The Inca tribe, whose conquests established and then extended the empire, became transformed with the passage of time into a dominant aristocratic class, the Incas proper or *orejones*—"big ears"—as the Spaniards called them from their characteristic practise of piercing the ears for an ornamental plug and enlarging the hole until the lobes hung nearly to the shoulders. The members of this class, bound to the sovereign by ties of blood and common interest, filled all the more responsible civil, military and ecclesiastical positions. When not on active duty in the provinces, however, they resided at Cuzco, the capital.

A step beneath the Incas on the social scale stood the Curacas or provincial nobility, from whose ranks came most of the lesser officials, the heads of centuries, phratries and tribes. In accordance with the cardinal Incaic principle of altering local institutions as little as possible, the chieftains of vanquished peoples were fitted into posts in the administrative hierarchy commensurate with their former positions, being removed only if they displayed irreconcilable hostility. The sovereign sought to win them over to active support of the imperial system by exemptions from local restraints, by generous gifts of property, servants and wives, and by grants of Incaic privileges in reward for faithful service. He further secured their fidelity by requiring their sons to reside at Cuzco—not only to serve as hostages but also to receive an Inca's education and thereby become imbued with the culture and attitude of the ruling class. By measures such as these the Curacas were gradually assimilated to the Incas, and the line of cleavage between conquerors and conquered was largely erased.

Between nobles and commoners, on the other hand, the line of demarcation grew correspondingly sharper and more rigid. The great mass of common people by their economic activities—mainly agricultural and pastoral—not only maintained themselves but also produced a surplus sufficient to support the classes which rendered only intangible services to the state: the officials,

nobles and priests. Such a surplus was assured, in part, by a body of sumptuary laws regulating and rigidly restricting the standard of living of the masses. They could not eat the choicer food delicacies or drink the more intoxicating beverages. They were forbidden to wear garments of fine wool or ornaments of gold, silver or precious stones. And they had no share in such prerogatives of the Incas and Curacas as the right to hold landed estates, receive an education, and practise polygamy.

The industrial life of the clan and village remained comparatively unchanged under the Inca régime. The conquering tribe divided all the cultivated land of the empire into three parts. The first and much the smallest portion belonged to the cult and was concentrated in the vicinity of the temples which its produce supported. The second portion, the property of the crown or state, consisted mainly of waste regions reclaimed for agriculture by the irrigation and other engineering projects of the conquerors. A small fraction of the state domain fell, through gifts from the sovereign for outstanding services, into the hands of individual nobles, sometimes as estates held for life only and sometimes as hereditary but inalienable and indivisible private property. The third and largest portion of the tilled land belonged to the centuries, which the conquering Incas were careful not to dispossess of their old clan holdings. Each century likewise owned communally its stretch of pasture and woodland, although the more extensive forests and grazing grounds were state property.

The arable land of the century was divided into strips of equal size, called *tupus*, each just large enough to support a married but childless couple. Some were tilled in common for the maintenance of the aged and incapacitated; the rest were allotted annually, under the direction of the centurion, to the heads of families, each of whom received one *tupu* for himself and wife, an additional strip for each male child, and half a strip for each daughter. On marrying, a son took over one *tupu* from his father, but a daughter's share reverted to the common fund. Each family cultivated its own plot and enjoyed undisputed possession of everything it raised. Hence the economic organization of the century was not, strictly speaking, socialistic or communistic, as some authorities have maintained. On the contrary, it followed the familiar pattern of agrarian collectivism, typified, for instance, by the Russian mir.

The agrarian community, however, became the basis of a truly socialistic superstructure. Instead of allowing free rein to personal interest and competition to achieve an automatic equilibrium of economic forces, the Incas substituted a rationally planned economy in which demand and supply were artificially regulated. The sumptuary laws stabilized and limited the demand, while the supply was cared for by a nationalized system of production superimposed upon the clan economy.

The first task was the support of the economically unproductive classes—the administrative hierarchy, the nobility and the priesthood. This was not accomplished, as we might expect, through taxation. Only in a few very exceptional cases did the state impose levies in goods upon its subjects. On the contrary, it followed the principle of the *corvée*, namely, that tribute should take the form of personal services. Every able-bodied householder or *puric*, besides cultivating his own plot of ground to support his family and cooperating with his clansmen in tilling the undistributed lands of the century to provide for its less fortunate members, was expected to devote a portion of his time and labor to

the service of the state. This contribution took the form, primarily, of labor on the lands of the crown and the cult. The men, while at work, were fed, entertained, and provided with seed and other necessities at public expense. The products contributed to the support of the official and ecclesiastical hierarchies.

The pastoral economy paralleled the agricultural. In the highlands each *puric* possessed a pair or two of llamas and had the right to use their wool and to kill their offspring for food. Small herds were owned communally by the centuries and privately by the Curacas. The crown and the cult, however, possessed enormous herds of llamas and alpacas. The *purics,* as part of their labor obligation to the state, took turns in tending these animals and performed assigned tasks at the periodic shearings and slaughters. The wool, hides and meat, of course, flowed into the warehouses of the state.

Although clansmen were privileged to secure small game on the woodland belonging to the century, the hunting of the larger wild animals was a state monopoly. Once a year the governor assembled the *purics* of his province for a great communal drive on one of the national forests. Surrounding a wide territory, the men advanced with a deafening din, penning their quarry in an ever narrowing circle. All beasts of prey—pumas, bears, foxes, wildcats—they slew on sight with arrows, darts and clubs. In the case of deer, they killed only a portion of the males, sparing all the does and best bucks lest the supply become depleted. The guanaco and vicuña, wild cousins of the llama, were captured alive with the bola—a rope weighted at the ends with stones. When thrown, this weapon wrapped itself around the legs of the animal, bringing it to the ground. The victims were shorn and then released except for a certain proportion of the males selected for slaughter. The hunters feasted on part of the meat. The remainder, together with the hides and fleeces, belonged to the state.

Mining, too, was nationalized. The Peruvians obtained gold by panning river gravels and extracted silver and copper ores in pits or short galleries. Miners were drafted for a term of one month a year and in this way performed their labor obligation to the state, which, of course, owned the product.

An important part of the tribute obligation of the *puric* consisted in labor in the construction of public works. As soon as a new province was conquered, for example, a complete census of its population, land and resources was taken; the monarch with his council laid plans for the construction of needed roads, fortresses, irrigation systems, etc.; and an army of engineers and drafted laborers was put to work. Mountain slopes were reclaimed for agriculture by terracing them with rows of stone retaining walls like gigantic steps. Swamps were drained and water was brought to arid lands by constructing systems of canals, reservoirs, aqueducts and sluices. The reclaimed lands became the property of the state, which could thus afford to leave the clan holdings intact.

Similar levies erected the Cyclopean fortresses, temples and palaces at Cuzco and elsewhere. The architectural skill of the Peruvians is attested by the fact that blocks of stone thousands of cubic feet in dimension were fitted to each other, without mortar, so accurately that a knife blade could not be inserted between them.

Drafted labor likewise built and maintained the roads. Two main highways traversed the empire from north to south, one along the coast, the other in the highlands. Numerous transverse and secondary roads formed a giant network converging on Cuzco. The

highways ascended mountains by steps hewn out of solid rock. They spanned streams on stone culverts, rivers on pontoon bridges, marshes on causeways, and gorges on marvelous suspension bridges moored to masonry piers.

At intervals of every two or three miles stood post houses, where two or more couriers were always in attendance. When a runner from the next station approached, a fresh courier would run alongside to learn the message or receive the burden and then dash off for the next post without slackening of pace. Every twelve to eighteen miles along the roads stood an inn with accommodations for travelers and a cluster of twenty to fifty small rectangular storehouses stocked with food, clothing and arms.

The rigid decimal organization of society, which appears so arbitrary at first glance, becomes comprehensible when we regard it as an adjustment to the system of tribute by labor in lieu of taxes. Lacking a written language, the Peruvians were able to keep records and deal with large figures only with the aid of the *quipu*—a thick cord from which hung a fringe of colored and knotted strings, the colors representing classes of objects, the number and position of the knots denoting numerals. Since the *quipu* lends itself to computation only in terms of decimals, the Incas could devise only one equitable way of levying drafts of labor, namely, by fixing a quota for a large group, assigning one tenth of the quota to each constituent sub-group, and so on. Thus, if 1,000 men were needed from a particular tribe for a construction project, each phratry would have to furnish 100, each century ten, and each decury one. If the units had varied in size, *e.g.*, if some centuries had had fifty *purics* while others had two hundred, the smaller units would have contributed disproportionately and the tribute burden would have been inequitably distributed. It was imperative, therefore, to maintain the various units at approximately their standard size.

Once a year each decurion reported to his superior the number of births and deaths in his ten families. These figures were transmitted through official channels to the provincial governor, who had them compiled by an accountant, reported the total to the emperor, and turned over the records to the official *quipu* keepers at Cuzco. On the basis of these statistics the state imposed a permanent levy upon each group which appreciably exceeded its ideal population. The surplus thus drawn off was, in part, formed into *mitimaes* or colonies, which were granted special privileges and exemptions, and were transported to man military outposts, to settle underpopulated areas, to introduce Incaic culture to backward regions, or to replace rebellious tribes removed to safer sections. From the surplus not absorbed in *mitimaes* were recruited two anomalous classes in Inca society: the *yanacuna* and the *acllacuna*.

The *yanacuna* consisted of men levied as youths for the personal service of the monarch. He employed them as palace attendants, devoted them to the temples for similar services, used them as porters in the army, presented them to officials as domestic servants or as serfs to till private estates, assigned them minor administrative posts such as the supervision of warehouses, or had them trained in specialized handicrafts. They lost their clan rights and also all duties except to their masters, but their status, though hereditary, was scarcely that of slaves. They fared, on the whole, rather better than the *purics*. Being in a position to gain the confidence and favor of their masters, they were frequently rewarded with rich gifts and even with landed estates and official positions, to which the commoner could never aspire.

The *acllacuna* or so-called "Virgins of the Sun" formed the second anomalous class. Selected at the age of eight or nine from overpopulous centuries, they lived in convents under the supervision of matrons. Some, at the age of fourteen, took vows of chastity and became priestesses. The majority, however, at the will of the emperor, became imperial concubines, married *yanacuna*, or were bestowed upon favored nobles as secondary wives. The *acllacuna*, too, lost their clan membership, yet acquired an enhanced social status.

These special classes, though never very large, nevertheless filled an important place in the Inca economy. Besides rendering personal service in palace and temple, they carried on the specialized arts and crafts. Except for them, a division of labor in production, other than by sex, scarcely existed in Peru. Each clan, indeed each family, was practically self-sufficient economically. Every commoner was a Jack-of-all-trades, conversant with all save a few luxury arts such as metal working and fine weaving, and it was these that were carried on by the classes in question.

Yanacuna smiths worked with gold, silver and copper. They understood how to make bronze by mixing copper and tin in the ore, and how to plate one metal with another by hammering and by the use of mercury amalgams. Perhaps nothing better reveals their skill and artistry than their ability to fashion golden butterflies with wings one tenth of a millimeter in thickness, so light and so well balanced that when thrown they soared like toy airplanes before falling. The precious metals and their products poured into Cuzco, which was a veritable El Dorado. The temple of the Sun, for example, had a golden garden where trees and plants, fruits and flowers, birds and insects were all of gold, and where grazed a herd of golden llamas under a life-sized golden shepherd.

The *acllacuna*, working in the convents under the direction of expert matrons, wove the fine fabrics of vicuña wool and supplied the ruler, the higher officials, and the priests with their rich garments. In skill and technique in the textile arts the ancient Peruvians have had no equals, even among European peoples. Their tapestries, for example, in harmony of colors, fastness of dyes and perfection of technique, are stated by experts to surpass the finest Beauvais and Gobelin products.

The collectivistic economy of the clan or century provided automatically for most of the needs of the masses. The superimposed régime of the state restricted popular consumption by sumptuary laws. It assured a surplus production of manufactured goods through the special classes of *yanacuna* and *acllacuna*, and of raw materials through the general requirement of labor on the lands, in the mines, and with the herds belonging to the state. What marks it indelibly as socialistic, however, is its system of distribution. It achieved an equilibrium of production and consumption, not through the free interchange of goods, but through state-supervised periodic distributions of the surplus production.

In this system the warehouses strategically located in clusters along the highways played a vital part. Into them flowed a steady stream of raw and finished products from the crown and cult lands, the state herds, the mines, the organized game drives and the specialized handicrafts. From them the state drew: (1) means of subsistence and luxuries for the ruling, official and priestly classes, their servants and the artisans, (2) food and military stores for armies on the march, (3) raw materials for manufacture into finished goods, (4) support for *purics* engaged in public work, (5) supplies to relieve regions stricken with famine or crop failure, and (6) consumption goods for

the masses in all cases where the latter could not supply themselves. Since the warehouses contained reserves of food sufficient to support the entire population for several years, and corresponding quantities of other articles, the system provided adequate insurance against privation. The supervisors made periodic reports, which were tabulated and preserved in the archives at Cuzco. Thus the authorities always knew the exact status and location of the reserves, and could order their transfer by porter or llama train from well-stocked regions to those with a shortage. The people received distributions of staples, such as meat, wool, cotton, seeds and tools, periodically, and of other articles whenever the statistics revealed a surplus above necessary reserves. Distributions, like levies, took place by successive allotments to tribe, phratry, century, etc.; each family thus received the same as its neighbor, irrespective of its individual needs. Under this system economic life pursued an even course undisturbed by the boom periods and depressions which result from leaving the adjustment of production and consumption to automatic forces.

Travel and transportation were public functions. No one used the roads except couriers, officials, soldiers, colonists, authorized pilgrims and porters. To be sure, the state carried on a heavy traffic in the interchange of regional products, but private trade was confined within very narrow limits. At local markets, held thrice a month, families exchanged—by barter, for there was no money—the surplus products of their fields and unneeded articles received from the state. These markets served principally to adjust the inequalities resulting from the rule-of-thumb system of distribution. The limited range of private property, the sumptuary laws and the state's participation in the circulation of goods effectually prevented the development of trade on a broader basis. Even foreign trade, as in Soviet Russia, was a government monopoly.

Inca socialism, absurdly idealized by some writers and as unjustly dismissed as a fiction by others, emerges from a survey of the facts, not as the product of a Utopian dream, but as a natural adaptation to a special set of conditions. To the conquerors it assured power, position and luxury; to the conquered, economic security, the essential preservation of local institutions, and probably an enhanced standard of living. Pragmatic rather than dogmatic, it sought, for example, not to extirpate commerce and private property on principle but rather to limit them on practical grounds. Socialism, linked with democracy in Marxian theory, was consistent in Peru with monarchy and aristocracy. The Inca system exerted a leveling influence, creating a uniform standard of living throughout the empire. But if it thus realized the ideal of equality, it was equality only within a given social class. It subordinated the individual to the state, regimented and controlled his life from birth to death and left little scope for personal initiative and ambition. On the other hand, it achieved an exceptional measure of law and order, it prevented the waste of natural resources and it eliminated entirely the hazards of poverty and involuntary unemployment. In general, it displayed many but not all of the virtues for which socialism has been exalted and many but not all of the defects with which it has been charged. We should not forget, however, that it was a working system and not a theory.

WHERE IS PHYSICS GOING?

By Professor R. B. LINDSAY
PHYSICAL LABORATORY, BROWN UNIVERSITY

EVERY one is interested in the newest trends of contemporary physics, and on all sides one notes a feeling of wonder at just what is going to happen next. It will doubtless be considered presumptuous on the part of any one to attempt an estimate of the probable direction of physical progress during the years immediately ahead. Indeed it would be possible to take the attitude that the attempt is meaningless, and to use as justification the dictum of the celebrated writer who said: "Going there is more important than getting there and to travel hopefully is better than to arrive." There is a sense in which the zest and fun of *doing* things scientific outweigh consideration of the aim and ultimate goal of these activities. Contemporary writers never tire of pointing out the essential disinterestedness of scientists in their search for knowledge for its own sake and the danger of any attempt to force scientific research into any specific channel. Nevertheless, a study of the history of science and physics in particular reveals the existence of certain methods of attack on physical problems which persisted through relatively long periods, finally to be supplanted by what seemed to be more promising schemes. Consequently, there can not fail to be interest nowadays in the question: What is likely on the basis of present evidence to be the general fashion in physical theories in the immediate future? It is with this question that we wish to concern ourselves in this paper.

In the first place, what is the task of physics? Reduced to simplest terms it is the description of a certain portion of human experience. This description is carried through by the building of physical theories forming the basis of what may be called the physical world, a world constructed in the mind of the physicist, but which he tries to make correspond as closely as possible to the world of experience. Physical theories are of many types, corresponding to the diversity of phenomena, but the natural aim dictated by both esthetic and economical reasons is to reduce their number to the smallest possible. The history of physics during the immediate past shows a tendency to emphasize two main types of theories which have received the names *mechanical* (or dynamical) and *statistical*. A mechanical theory of a set of physical phenomena is based on the assumption that the thing which in the physical world corresponds to the phenomena in question is a mechanical system, *i.e.*, essentially a system of particles moving in space and time in accordance with the principles of classical mechanics. The details of such a theory require no consideration here. However, there are two very significant properties of the method of physical description involved in a mechanical theory. The first is that of *determinism*, the second *reversibility*. By determinism is meant simply the fact that if the state of a mechanical system is known at any instant its state is completely determined for all time, past or future. Thus the knowledge of the state of such a system at any one time enables one to predict what it will be at any other time. This property of determinism or predictability is of course in agreement with the doctrine of causality and has in the past been considered one of the strongest points in favor of mechanical

theories. During the last century this method was pursued with relatively great success, as may be seen from the mechanical theories of fluids, acoustics, electrical currents, optics, etc. The implication of reversibility is that there is no preferred direction of change involved in a mechanical system. The equations of classical mechanics do not distinguish between the positive and negative directions along the time axis. By a suitable change in conditions a mechanical system may traverse its path backward. A ball rolling down an inclined plane will, if the opportunity is offered, roll up again and to the extent that it constitutes a dynamical system will roll up to a height equal to that from which it originally fell. The actual experiment does not have quite this result, that is, the ball does not reverse itself exactly: we have to admit that its behavior is not quite reversible. In fact, observation shows that the phenomena of nature are always more or less irreversible, and this might have constituted a very serious objection to the use of mechanical theories for their description were it not for the fact that in a great many cases the irreversibility can be neglected in comparison with more important aspects of the phenomena.

The second important type of physical theory, namely, the *statistical*, is characterized by its renunciation of the concept of determinism and its emphasis on the average behavior of physical systems. The kinetic theory of gases, for example, is a statistical theory in that it makes no attempt to follow the destiny of each individual molecule of a gas, *i.e.*, to predict exactly what its position, velocity, energy will be at any given instant; rather it seeks merely to know how many molecules on the average will lie in a chosen volume, how many molecules on the average have their velocities included within certain limits, etc. By this method much valuable description of the behavior of gases has been made possible in good agreement with experimental facts. It would be quite wrong to suppose that such a theory does not predict new phenomena; we must only emphasize that its prediction always refers to average behavior and that therefore its assertions have only a certain degree of probability. Statistically speaking, the second law of thermodynamics, for example, describes the behavior of physical systems only with a more or less high degree of probability, never with certainty. Moreover, by virtue of its use of probability the statistical method involves the possibility of describing irreversible phenomena. Hence it stands in sharp contrast to the method of classical mechanics.

A question which is provoking considerable discussion among physicists at the present moment is: Which of these two types of theories is to prevail ultimately in the construction of the physical world? The reason for this eager interest is to be found of course in the rapid development of the newer theories of the structure of matter based on the quantum concept. In the previous century the choice between mechanical and statistical theories was largely decided by the criterion of convenience. Whenever the problem was one of describing the behavior of a system with a large number of degrees of freedom (*i.e.*, containing a great many entities) the statistical method at once suggested itself as the natural approach. There was, however, no suggestion that the strict application of classical mechanical concepts to such a problem was wrong in *principle*. This situation has been radically altered by the introduction of quantum mechanics. If the latter is expressed in terms of our usual space and time concepts, it involves the necessity as a matter of principle of treating statistically the behavior of even a single

electron. Through the famous indeterminacy principle of Heisenberg it renounces the possibility of predicting the state of an electron or system of electrons at any instant and reduces our knowledge of such states to probabilities only. This amounts to indeterminism in the microscopic realm of atomic physics and therefore *a fortiori* logically to indeterminism in all physical phenomena. At any rate to many physicists there seems no way of escaping this conclusion. It has naturally excited much interest among all those to whom the progress of science is a matter of moment, for it appears to mark a decided trend away from the point of view of that classical mechanics to the use of which so much past progress has been due.

The conclusion just mentioned, however, has by no means gone unchallenged and it will be worth while to examine the views of some of those who are inclined to look at the situation more conservatively. Foremost among these is Max Planck, himself the propounder of the quantum theory which has had so much to do with the development of the new tendencies. He emphasizes the view that in any discussion of the methods of physics one must be careful to distinguish between the world of experience (*viz.*, the world of laboratory operations, etc.) and the physical world which is created by the mind of the physicist to describe the former. No one can believe in exact determinism in the former, for, in spite of the approximate regularity of experience, not even the most delicate of physical experiments are *exactly* predictable in their results. Nowithstanding this, physicists have not hesitated to use the idea of causality or determinism in the physical world and in general, we must all realize, with considerable success. The indeterminacy comes merely with the transition from the physical world to that of experience. In similar fashion one might argue that it should be possible to construct a quantum mechanical theory which is completely deterministic and which moreover leads to laws that are found to describe experience in the atomic realm with as great accuracy as that with which the laws of classical mechanics describe large-scale physical phenomena. Now as a matter of fact this is admitted to be true as long as the primitive concepts of space and time appear nowhere in the theory or in its application. It is clear that it is the use of these ideas which leads to the new indeterminism. Foregoing or renouncing these implies, for example, that it is really meaningless in physics to contemplate the simultaneous measurement of the position and velocity of an electron, and in general that the space and time concepts which we use in macroscopic physics are wholly inadequate to handle microscopic phenomena. There is indeed a difficulty about this view which we shall examine a little later. Into the more metaphysical aspects of Planck's views it is probably unwise to enter here at any length. But it is felt that physicists will be mildly interested in Planck's speculation about an ideal mind which is sufficiently objective with respect to our world that it is able to predict all phenomena, thus transcending mere man, who, being himself a part of nature, is never able to achieve complete objectivity in his study of it.

The attitude of Schrödinger, the creator of the wave mechanics which has proved such a powerful weapon in the theoretical attack on atomic problems, is of course also of great significance. While probably less conservative than Planck he is plainly cautious in his emphasis on the truism that no one can prove that a deterministic theory of all physical phenomena is not ultimately possible. To be sure this is rather cold comfort to those who feel that they are

confronted by an existing condition which demands a clear-cut attitude rather than one of vacillation. However, Schrödinger strengthens his thesis by calling attention to the fact that even in classical mechanics there exists an element of indeterminism which has to be removed by appropriate devices. We recall, for example, that if we know merely the *position* of a particle at a given instant the laws of mechanics do not suffice to predict its position at any other instant; in fact, the latter is undetermined. In order to make it determinate it is, of course, necessary to specify the *velocity* as well as the position at the given instant. It is only when this is done that the past and future states of the particle are predicted. Instead of the velocity one may use the position at two separate instants. If the latter are close together we are of course led to the concept of velocity in differential notation. Determinism in mechanics thus results for the use of the appropriate number of initial or boundary conditions[1] as well as from the nature of the laws which are employed. The thought occurs that a similar situation may exist in quantum mechanics: that if we were to introduce a sufficient number of parameters the indeterminism involved would disappear. No one appears to have considered this possibility seriously, possibly because the fixation of boundary conditions (no matter what their number may be) implies measurement, and the indeterminacy principle of quantum mechanics denies the possibility of a simultaneous measurement of the quantities necessary for a specification of the conditions. This is equivalent to saying that any attempt to localize the electron, or any particle for that matter, involves a renunciation of knowledge of its subsequent path. Let us examine a little more closely the corresponding situation in classical mechanics. The very concept of a particle as having a position in a given reference system at every instant implies that it possesses in its motion a *continuous* path. Now no experimental observation is ever competent to determine such a path, for no such observation can ever hope to fix anything but a finite, discrete set of points. Strictly speaking, in so far as a physical law purports to be a description of laboratory operations and observations, the functions used should for this reason be discontinuous. However, in the method of description employed by classical physics, we avoid what would be considered undue complexity by smoothing out the discontinuous functions into continuous ones, *i.e.*, we draw smooth curves through discrete points by a process of judicious interpolation. This is not the place for a thorough investigation of the justification of this scheme, which indeed might strike the casual non-scientific observer as being rather gratuitous, not to say risky. We may merely remark that in general the physicist feels he is safe in making the interpolation in question if there exists an operation or set of operations by which he can at any rate in principle check *any particular* interpolated value. To make this point a little clearer, let us imagine the special case of the path of a projectile. We suppose that there exists an experimental scheme for plotting the position of the projectile at various instants of time. A smooth curve is drawn through the various positions and is called the path of the projectile. For we feel that our method would allow us to ascertain the position at *any* other finite discrete set of time instants and hence to check the curve drawn on the basis of the first set. Of course, we must also make the assumption that it is very unlikely that the new

[1] See R. B. Lindsay, "The Significance of Boundary Conditions in Physics," SCIENTIFIC MONTHLY, Vol. 29, 469, 1929.

set of positions will fall very far away from the curve. If we were to encounter a situation in which there no longer existed such a means of checking the interpolation, we might be wiser not to attach much value to the smoothed-out curve and function. Now it is possible to take the stand that this is precisely the situation we encounter in atomic problems. We indeed have experimental devices which make possible the photography of so-called "tracks" of atomic particles, but it must not be forgotten that we have not that measure of control over such experiments which makes possible the verification of the interpolation involved in the pictures of such tracks. The situation is even more hopeless when we consider the "motion" of bound atomic particles like electrons in an atom. There would appear to exist no operation by which such "motion" can be experimentally observed. The conclusion which some would like to draw from all this is that there is then no meaning to be attached to such motion or to the paths of such electrons; hence atomic theory should not involve such considerations at all. This attitude was to a considerable extent responsible for the introduction of the new quantum mechanics (Heisenberg) in 1925. Obviously, it would tend to make the application of the indeterminacy principle to atomic motions illusory and would leave the way open to a deterministic theory in which atomic paths and motions have no place. The possibility of this view-point has already been indicated above in our discussion of Planck's view.

At this very point, however, we encounter a grave difficulty which has been emphasized by Niels Bohr, the founder of the quantum theory of atomic structure, whose work is responsible for the whole of contemporary atomic mechanics and who has probably thought more deeply about the methodology of modern physics than any other man. Bohr's attitude is an interesting mixture of the conservative and the radical. It is conservative in the sense that it is founded on the conviction that physicists are unable to get away from thinking in terms of space and time since all experiments are carried out with these categories uppermost in mind. On the other hand, Bohr believes quite thoroughly that we are forced to renounce a unified, causal view of nature. This renunciation is involved in what Bohr calls the principle of "complementarity," which expresses the hypothesis that we must in our analysis of nature necessarily encounter mutually exclusive modes of description which may therefore be said to stand with respect to each other in a complementary relationship. It must be stressed that there is involved here something deeper than mere alternative theories, either one of which may be applied indifferently according as we wish to stress now one and now another aspect of the situation. Such theories have of course long been recognized: for example, so far as the phenomena of calorimetry are concerned it is a matter of indifference whether we use the theory which looks upon heat as a substance or that which considers it a form of energy; again, so far as the large-scale phenomena of electrostatics are concerned, we may employ indifferently the theory which looks upon electricity as a *continuous* fluid or the electron (atomistic) theory. The natural aim of physics is to remove theories from the indifferent class by imposing more stringent requirements on them. Thus, to consider again the heat illustration, it is well known that the energetical theory of heat is much more competent to describe the whole range of observed thermal phenomena than the substantial theory. Hence from the larger point of view it is no longer a matter of indifference which theory is held. We are present-

ing this digression for the purpose of emphasizing the wholly distinct and novel place occupied by the complementarity idea in contemporary physics. The significance of the latter may be made clear by one or two examples. It is now well known that in the description of optical phenomena all observations having to do with the propagation of light are best described in terms of the wave theory, while all observations connected with the emission and absorption of light are best handled by means of the quantum theory, which has introduced into optics the atomistic view-point. No one has ever succeeded in representing *all* the phenomena of light by means of *either* theory, and the point of view of Bohr is that there is an essential limitation in human methods of describing experience which prevents the building of a single unified theory of light. If we wish, for example, to describe the interference patterns which are formed when light from a given source passes through two openings in a screen and then falls on another screen, we must use the wave theory. If, for example, we were to attempt to account for the patterns from the light quantum or photon point of view we should have to say that more photons fell on one part of the screen than on another part. This would in turn involve tracing the paths of such photons. But the attempt to do this experimentally only leads to the complete obliteration of the interference pattern or the very thing which is to be described. It is true that many attempts have been made to discuss light propagation in terms of photons. It must be admitted that so far they have not been successful. Bohr's thesis is that in the very nature of things they never can be successful, for the wave description and the particle description are mutually exclusive, complementary methods: the use of one automatically excludes the use of the other. It may indeed happen that some one *will* discover a way to reconcile the two points of view and make them essentially indifferent hypotheses. In that event Bohr's generalization would fall. It must be admitted, however, that he has a strong case. The situation encountered in optics occurs in every case where the Planck constant of action "h" appears, and therefore leads to the feeling that wherever the quantum theory has to be used we are at a threshold, so to speak, marking the limitation of human descriptive ability. To take another illustration, the description of atomic phenomena appears to demand the quantum theory. Thus an atom is assumed to exist only in certain so-called "stationary" states of great stability, and every alteration of the atom must take place from one of these states to another. Now suppose one were to try to describe such an atom in terms of space-time motions of particles (*i.e.*, the assumed elementary constituents of the atom). This would ultimately involve measurement of position and velocity of the atomic particles. But the attempt at measurement would so disturb the atom that the stationary state concept would no longer have any meaning. One might object that it should be possible to estimate pretty exactly the amount of disturbance which is produced by the measuring instruments. Strictly speaking, this is possible only if the instruments themselves can be included in the system (in this case, the atom) being investigated. But the whole purpose of a measuring instrument is to yield information about something objective to and separate from itself. Hence it can not be included in the observed system without losing the objectivity which is the essential feature of scientific description. We therefore reach the conclusion that the quantum theory concept of stationary atomic states is complementary

to a space-time description of atomic behavior. Each mutually excludes the other.

The idea of complementarity may be made somewhat clearer by a simple experimental analogy. Imagine a rectangular box divided into two equal compartments with a single die in each part. The box has a glass top, but there is further an opaque cover which can slide back and forth concealing entirely one compartment from view while the other is exposed. The sliding of the cover is so arranged that when it takes place an impulse is communicated to the dice which is equivalent to shaking them.[2] Now when the slide covers one compartment an observer can note the aspect of the die in the other compartment. This is, so to speak, equivalent to a measurement. In order to conduct the associated measurement of observing the aspect of the other die, the cover slide must be moved over so as to leave the corresponding compartment visible. But the process of doing this creates a disturbance so that when the aspect of the second die is noted, the observer no longer knows which face of the first die is uppermost. We may say that his knowledge of the aspect of the one is complementary to his knowledge of the aspect of the other. Any attempt to note both *exactly* is doomed to failure: he can at best estimate the probability of any pair of associated readings. If he wishes to know exactly the aspect of the one he must renounce exact knowledge of that of the other at the same time. It is important to realize that the reason for this complementarity is precisely the disturbance involved in the measurement and the impossibility of estimating the magnitude of this disturbance. To be sure, an observer who understood thoroughly the construction of the box and knew the exact relationship between the impulse communicated to the die and the motion of the slide might be thus enabled to predict the precise aspect of each die for every observation. But even then, since he can never see both dice simultaneously, he could never be exactly sure that his theoretical prediction was true and indeed could never verify it except by making another "measurement," which would again introduce the necessity for a further calculation, the verification of which would necessitate still another measurement, and so on indefinitely. Bohr insists that this is quite analogous to the actual situation existing in physical description. Every attempt to account theoretically for the disturbance introduced by a given measurement involves another measurement for its verification: one is therefore led to an infinite series of observations before exactness can be obtained. In large-scale physical observations the disturbances may be made so slight compared with the measured effects that they *may* be sufficiently accounted for and compensated within what we call the limits of experimental error. Hence in this realm we do not feel any drastic need of the complementarity idea. But the situation is different in the microscopic domain of atomic measurements, for here the disturbances introduced by the measurement are of the same order of magnitude as the quantities being observed. Here then the essential limitation of our descriptive ability makes itself most keenly felt. Bohr's conviction of this limitation as leading to an inevitable renunciation of a complete understanding of physical phenomena in terms of both space-time concepts and causal explanation has led him to the interesting extrapolation that for similar reasons we must renounce a complete understanding of life and accept it as an ele-

[2] A box of this nature was on exhibition in the Danish Room of the Hall of Science during the Chicago Century of Progress Exposition, 1933.

mentary fact. All our attempts to learn what life is involve disturbance to living processes which enable the living organism to conceal from us the information we seek.

Such then is the extremely interesting attitude of Bohr! In so far as physics is concerned it is supported by such a wealth of illustrations as to make its plausibility plain. At the same time there are doubtless some who will look upon it as the expression of a kind of "defeatism" psychology. Does it not perhaps confess human limitations too readily? If accepted whole-heartedly might it not color in too pessimistic fashion the immediate future of physics? We realize, of course, that the complementarity idea is based wholly on the quantum theory, *i.e.*, on the existence of the quantum of action, "h." If it were not for the atomicity of action the principle would imply no more than our usual admission of error common to all measurement. But it is precisely the assumption of the existence of a *smallest* quantity of action which forces us to admit the fundamental limitation implied in the principle. Now, of course, the quantum theory was invented to describe certain phenomena. There can be in the nature of things no proof that there exists no other possible theoretical description of these phenomena than that involving the quantum of action. Human ingenuity may yet invent a new point of view, and the reading of the history of physics does not encourage idolatrous worship of current physical theories, no matter how temporarily successful they may appear to be. Does it not then seem rather hasty to infer a fundamental limitation of human ability to describe natural phenomena from the success of a single physical theory? Some may prefer to believe that such a deduction from a physical theory casts extra suspicion on the latter rather than strengthening our belief in the former. The quantum theory has been so very successful, however, that the burden of proof probably falls on those who would oppose it, no matter how strongly they would like to see the embarrassing "h" taken out of nature!

Another important point in a critique of the complementarity idea is the rôle which space and time play in physics. About this much has been written, but it seems certain that there is still much left to argue about. It is difficult to believe that the primitive space and time notions in terms of which physical operations are carried out and physical description is made have reached their final form. We are forced to conclude that if man has evolved, his space-time orientation has also gone through an evolutionary process and there seems no reason to suppose that this process is now complete. Indeed our views of space and time have already in relatively recent time undergone considerable change as far as their scientific use is concerned in the development of the theory of relativity with its introduction of non-euclidian space and four dimensional space-time. One may remark that these matters may have little influence on people's primitive concepts. But that is not the important point. The significant thing is that for the sake of progress in physics it has already been considered desirable to modify and refine the primitive ideas. Hence there can be no artificial limit imposed on this process. As an illustration the present author would like seriously to propose the ultimate elimination of the use of the concept of time in physics. When it is considered that in physics time enters only as a variable parameter whose values may be put into one-to-one correspondence with the points on a line, *i.e.*, a non-denumerable continuum, and is introduced merely for the more convenient comparison of physical systems, and when it is further considered that

all time measurement reduces essentially to space measurement using arbitrary physical systems (*i.e.*, various kinds of clocks) the interesting question arises whether ultimately one might not avoid some of the embarrassments of contemporary physics by abandoning the parameter altogether in favor of direct comparison of physical systems. This is, to be sure, not the place for a complete airing of this view. It is merely a concrete suggestion as to how our use of space and time in physics may alter and in such a way as to remove the necessity for such a principle as that of complementarity, by removing the very concepts in terms of which the idea of complementarity is expressed. Such a step would probably make physics more "difficult." But that has been said to be the case with the introduction of almost every physical theory involving a conceptual change. The argument that a physical theory shall be *simple* has proved illusory. All we can ask is that it shall yield a set of laws (*i.e.*, relations among symbols) which, when the symbols are properly identified, shall agree with experimental observations, the latter being ultimately nothing but pointer-readings. The aim of theoretical physics is to develop new laws which subsume existing experimental observations more completely and moreover predict new ones, so that there shall exist no laboratory operation, the resultant pointer-readings for which are not predictable in advance.

The point of view of complementarity strikes so deeply at the concept of deterministic description that a thorough critique is hardly possible within the limits of an article like the present which confines itself to pointing out general trends. It is, however, rather tempting to consider briefly one more possible method of making progress in physics and overcoming present dilemmas. Up to this point in our discussion we have tacitly assumed, as is always done in theoretical reasoning in physics, the laws of Aristotelian logic, *viz.*: (1) The law of *identity*—everything is identical with itself, which really expresses the assumption that definite concepts are possible and that once a thing has been identified in clear-cut fashion it retains that identity; (2) the law of *contradiction*—a thing can not both be and not be, *i.e.*, the same object can not be both hard and not-hard at the same time and place, or soft and not-soft; (3) the law of *duality* or the *excluded middle*, as it is more commonly called—a thing must either be or not be, *i.e.*, an object must be either hard or not-hard, there is no third possibility. Of two assertions which really contradict each other, one must of necessity be true. In the third law it must be emphasized that the assertions must be contradictory and not merely opposite. Thus the law does not say that an object is necessarily hard or soft. All logical thinking as commonly understood can be shown to depend in the last analysis on these so-called laws of thought. In particular, all the symbolic reasoning in mathematics which is used in the development of physical theories has employed these laws as fundamental. Until rather recently no mathematician or scientist had thought seriously of questioning them. Presumably logicians have for a long time realized that they form the basis only for a *two-valued* logic, that is, one in which all propositions are either true or not-true; putting it alternatively, there are only two qualities associated with a proposition—*affirmative* or *negative*. The existence of a many-valued logic in which propositions may have other values than true or not-true is well established and their properties have been studied.[3] Among other things it

[3] See, for example, C. I. Lewis, *The Monist*, 42: 481, 1932.

turns out that for a many-valued logic the law of duality may cease to have any meaning. This might appear to have only a transient theoretical interest. However, certain mathematicians[4] have tried to see what happens in mathematical reasoning when one excludes the law of duality. An example, given by Brouwer, relates to the problem of the existence of a number k expressing the number of digits in the decimal representation of π at which the sequence 0123456789 begins for the first time. It is not provable that such a number exists; it is not provable that such a number does not exist. Presumably the only course of action with respect to such an example is to continue to carry out the expansion of π. It is at any rate *conceivable* that the sequence will occur somewhere and then the question would be answered. But until this result eventuates, the above conclusion can hardly be avoided if we wish to say anything about the problem at all. Possibly some would be inclined to say that this is precisely what we ought to do, *viz.*, keep silent. But how shall we react to the following paradox of Bertrand Russell: "There exists in a certain village a certain barber who shaves *all* those and *only* those who do not shave themselves. Question: Does he shave himself? The answer is that he neither does nor does not! As far as this village and this barber are concerned the law of the excluded middle has no application. We may object that this village is a decidedly peculiar one, but the fact remains that it and its paradoxical barber are thinkable. Now such considerations might be considered to possess little value for physics. However, it is a fact that recently[5] the proposal has been made that many-valued logics be seriously considered in the further development of theoretical physics. Zwicky's so-called "principle of flexibility of scientific truth," in accordance with which progress in physical research is to be accelerated by uniformly questioning all absolute physical statements, has indeed been shown[6] to have no essential connection with many-valued logics. However, the idea has been put into circulation and will undoubtedly stimulate speculation on the part of those who feel we are too greatly restricted by our customary two-valued logic. In a three-valued logic, for example, the truth values "true" and "not-true" might be replaced by the values "true," "not-true" and "indeterminate." With such a logic there would then be no dilemma with respect to the propositions: the electron is a particle, the electron is not a particle, for now we should admit the third possibility that "it is indeterminate whether the electron is or is not a particle." This might seem to be a trivial way to get out of a difficulty which physicists like Bohr consider so fundamental for physical description. The only point that might be made (of course the above is merely one illustration) is that the adoption of three-valued logic would completely change our attitude towards some of the now apparently puzzling problems and leave us more freedom in the interpretation of new experimental results. Certainly one might conceivably take this attitude: the principle of complementarity viewed now as a fundamental limitation to physical description may actually be a result of our retention of two-valued logic in our reasoning and may disappear as an important physical principle as soon as a three-valued logic

[4] Notably Brouwer, *Zs. f. Mathematik*, 154: 1, 1925.

[5] F. Zwicky, *Phys. Rev.*, 43: 1031, 1933; also E. T. Bell, *Phys. Rev.*, 43: 1033, 1933.

[6] H. Margenau, *Philosophy of Science*, Vol. 1, No. 1, p. 118, 1934.

is adopted. Naturally the question as to how advantageous such a step would be in accelerating physical research and knowledge can only be answered by the reconstruction of theoretical physics, using the mathematical analysis appropriate to the more general logic and the application of it to the newer phenomena. So far as the writer is aware, no serious attempt at this interesting problem has been made.

Most physicists will probably be inclined to believe that the possibilities of Aristotelian two-valued logic have not yet been exhausted. The total amount of theoretical physical literature published since the development of classical mechanics is relatively enormous, and it is an interesting speculation to think of how many ideas full of fertility for the developments to come may possibly lie buried in this mass of past "archives." One need only recall how completely Hamilton had worked out the connection between particle motion and wave motion about a hundred years ago—a work which was, so to speak, lying in readiness for its later application in wave mechanics. There will doubtless continue to be new things under the sun in physics, but as always they will continue to evolve out of the old ideas, the permutations and combinations of which are almost numberless.

MODERN SCIENCE, THE HOPE OF CIVILIZATION

By Dr. M. LUCKIESH

DIRECTOR, LIGHTING RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY

Two persons are gazing at the night sky studded with stars. One is familiar with the facts of astronomy; the other is not. To the one, there is order in that apparent disorder. To the other, the starry sky appears as a chaos. The one knows that only a few thousand stars are visible. The other multiplies these into an uncounted myriad. Modern science, through systematic measurements, has brought order out of that confusion of stars. It can do the same for any apparent chaos of nature or of civilization, if its method and the resulting facts are adequately applied.

In unprosperous times, the muddle of our sociological world is conspicuous. But, amid all the endless talk of causes and cures, how often is the simple explanation presented? The cause of our economic chaos is lack of adequate knowledge. If so, the cure becomes obvious. The muddle of civilization has always existed, but modern science possesses the purpose and method which should eliminate the chaos eventually. It has worked wonders in the relatively small portion of civilized activities which it has already invaded. By looking at its material achievements—airplanes, radios and the like—one is likely to conclude that this is a scientific age. But, looking at the sociological world as a whole, one must conclude that this is an unscientific world. While the physical sciences are learning the secrets of atoms and stars, economists, politicians and governments are chipping flints in a Stone Age sociology.

Every person interested in the great currents of civilized progress and in sociological institutions should be interested in the purpose and method of modern science. Extensive understanding means an extensive faith; and this is essential if the necessary social inventions are to be made and applied.

On every hand are found the applications of modern science which contribute to convenience, comfort and other joys of living. You have heard and read many stories of specific achievements of scientific knowledge and you will learn of many more. I could add another story of another success, but I shall speak of modern science, not because it needs spokesmen for itself, but because, in the extension of its purpose and method, lies the hope of civilization.

Modern science is a great movement against the unknown. Its purpose is unchallengeable. It aims to understand by knowing the truth. Its method is uniquely dependable. It is a new kind of strategy which aims to establish the facts, unwarped by such human frailties as prejudice and egoism. The harvest of this movement is tested and testable knowledge, therefore, incontestable knowledge. Any of the major sciences, or uncounted minor ones, is the coordination of facts in a sector of knowledge.

The success of modern science is found not in mind but in method. Great minds are not a monopoly of any single era of civilization. Aristotle possessed one of the great minds, but in accordance with the method of early centuries, he philosophized; he did not experiment. He believed to be true that which appeared to be true. For example, he thought that if two balls of equal size, but of unequal weight, were dropped from a height the heavier

would reach the ground first. He preached what he believed but had not proved. For many centuries that statement was accepted as truth until Galileo tried the experiment. He dropped the two balls from the leaning tower of Pisa and they reached the ground at the same time. This was the real beginning of a systematic accumulation of tested knowledge. The movement of modern science is not without its speculations and theories. But these are tentative and are labeled so. They are accessories after the facts. They are temporary lines of communication to be modified as rapidly as new facts require. The facts always remain supreme in modern science.

No idea or movement—not even a child—has a perfectly definite time or place of birth. Its ultimate beginning is somewhere in the mists of uncertainty. But everything has a practical beginning—a point where it began in earnest. So it is with modern science.

In Europe the Middle Ages were dark indeed. Civilization was struggling in its usual confusion. War and religion were the two outstanding occupations. Eventually, religion celebrated its survival with an intense fervor which built the great cathedrals. But, with all its good intentions, men's minds were more or less shackled by the dominance of man-made precepts, edicts and beliefs. Freedom in thought and action had feebly struggled for centuries. A declaration of independence in these matters was awaiting the next great revolution in civilization. It was a natural result of the great awakening which we term the Renaissance. Ridding their minds of the mists of centuries of philosophical dreaming, thinking men declared that nature could be understood and was worth understanding.

Modern science is just as much a human movement in the midst of humanity as any other movement. It has the same right to a symbol and a shrine as other movements. Born in the late Renaissance, Galileo was the right man, in the right place, at the right time. He was the first outstanding exponent of scientific method wherein is found the irresistible power of modern science. By his achievements in thought and action he gave the first great impetus to the movement which we call modern science—and he symbolizes it so well. To pay him homage, let us transport ourselves to Florence, Italy. Here, amid the tombs and statues, the palaces and art galleries, our imagination revives the human struggles for freedom of expression in all its senses. We seek out a modest church and enter the dim interior. The shadows, reminiscent of the glorious era of the Renaissance, are peopled with the spirits of great men and we remember best the good ones. After a few paces, we find ourselves on a spot that preeminently deserves the glorification of modern civilization. We stand between the tombs of Michelangelo and Galileo. It is impressed upon us that the city which gave the greatest gift to Art also gave the greatest gift to Science. As we stand there with deepening reverence, we note that Michelangelo died the year that Galileo was born. In our imagination we see the failing hand of that superb creator of the beautiful passing the scepter from art to science. In our imagination we hear Michelangelo saying: "The Renaissance artists questioned the old and created the new. They have shown that the world may be beautified superficially. But knowledge alone can supply the understanding which will reveal the third dimension as well. And only perfect and complete understanding can beautify the world through and through."

The substance of that imaginary statement by the old Michelangelo to the young Galileo should be the theme of the

lives of all who are a part of the movement of modern science. It might well be the theme of life for every one, for to understand is a high purpose. Furthermore, understanding, born of incontestable knowledge in all the sciences—physical, biological and sociological—is the only dependable cure for all the ills of ignorance—and this means most, if not all, ills of individuals and of civilization. In reality, or in imagination, all civilized persons should visit that spot in that church in Florence. It is the shrine of modern science. While there, they might pledge themselves to learn to separate incontestable facts from the common confusion of prejudices, assertions, preconceptions, beliefs and even superstitions.

Modern science, with its cold facts and calculating method, is generally supposed to be devoid of beauty and human interest. This is not true. Any science is an array of cold lifeless details; but so is any other structure, even the human being. The parts of a huge locomotive, when strewn on the floor of the factory, are uninteresting. But assemble the parts and put the locomotive into action. Then who will say that it is without beauty and human interest! The greatest masterpiece in painting consists of an array of material facts. The master, while painting it, was building a structure. His method was cold and calculating; every stroke was deliberate.

In the great movement of modern science are found the same intense loyalties, heroisms and sacrifices as in any other movement. Certainly, it is unexcelled in the beauty of its fairness and purpose. Certainly it recognizes no insurmountable barriers. Certainly, it is unlimited by boundaries, for its natural domain is the boundless unknown. All this is expressed in beautiful lines by Tennyson.

> Flower in the crannied wall,
> I pluck you out of the crannies.
> I hold you, root and all, in my hand.
> Little flower—but if I could understand,
> What you are, root and all, and all in all,
> I should know what God and Man is.

Modern science may not reach that far-off goal, but it moves irresistibly toward it.

WHAT'S THE MATTER WITH WHEAT?

By Dr. C. G. WILLIAMS
DIRECTOR, OHIO AGRICULTURAL EXPERIMENT STATION

WHEN matters go wrong in this country from an agricultural standpoint, it is pretty safe to ask, "What is the matter with wheat?" Wheat troubles are soon communicated to other agricultural products, and, when the farmer begins to slip, other industries will not be far behind. It will be recalled that when our Western congressmen thought that matters were in a bad way for the farmer some ten years ago they brought forward the first McNary-Haugen Bill, which was intended primarily to bring about a better price for wheat. Fortunately, or unfortunately, President Coolidge vetoed this bill.

But wheat was not to be held down for long. Responding to what some have ironically called the "divine law" of supply and demand, it rose decidedly in price and congressmen felt easier for a year or two. Soon, however, other surpluses appeared upon the horizon, and Messrs. McNary and Haugen again forged to the front with another bill, only to be checkmated by the same president, as well as a little later by President Hoover.

Matters drifted for a time, seemingly from bad to worse. The country appeared to be in reverse, moving rapidly in the direction of the bottomless pit. It seemed impossible for those in command to help matters. Realizing that something had to be done and being given the opportunity for action in the national election of 1932, the people of the United States seized it and removed the man at the wheel, somewhat violently, to be sure, and put another in his place. It is perhaps a little early to evaluate this action, but on the whole the people seem willing to try almost anything.

With a newly elected Congress apparently anxious to give the administration a free hand in the solution of the nation's problems, it was not long until the latter came forward with an agricultural program, and occupying a prominent place in this program was wheat.

Why wheat?

There are several reasons why wheat claimed early attention. It is a crop which is grown in every state in the Union and in practically every country on the globe. We have quite authentic statistics from over fifty countries, but as yet none from the planets Venus and Jupiter.

Next to gold, wheat is perhaps our best measure of value. Many people have acquiesced in using wheat as a standard with which to measure or compare other commodities and are wont to say "as good as the wheat."

And wheat has some advantages over gold. It would be more desirable than gold, "yea, than much fine gold," if one were shipwrecked on a desert island. Wheat bread is the all but universal staff of life.

As has been intimated, more people in this country are interested in growing wheat than in any other crop. Probably more people look to wheat, not only as a source of food but as a source of cash with which to pay taxes and to purchase the necessities of life, than to any other one crop.

Accordingly, wheat has got into politics. The wheat farmer is probably more articulate than other farmers. Given a good price for wheat and the world will move forward with very little grumbling, but let wheat get in the dumps and there will be "weeping and gnashing of teeth." Where teeth are lacking they will be furnished by the Farmer's National Holiday Association.

Why is it that the price of wheat has been lower in 1933 than at any time in more than a century? There are several reasons why this is so. One is that the whole world has been enveloped in a great financial depression and has had to tighten its belt in lieu of eating its normal rations. Another has to do with the wheat acreages of the world. What has happened here?

The great wheat-producing countries of the world are Russia, United States, Canada, Argentine and Australia. As an average of the years 1909–13, Russia cultivated 57,430,000 acres of wheat. Of course during the war Russia's acreage dropped very low, but in 1931–32 it rose to 92,070,000 acres, an increase of 60.3 per cent. over the pre-war period.

The wheat acreage in the United States averaged 47,100,000 in 1909–13 and rose to an average of 59,910,000 acres in 1926–30—an increase of 27.2 per cent. The figures for Canada are 9,940,000 acres in 1909–13 and 23,930,000 in 1926–30, an increase of 140.7 per cent. The acreage for Argentine was 16,051,000 in 1909–13 and 19,430,000 in 1926–30, an increase of 21.0 per cent. For Australia the wheat acreage was 7,600,000 in the pre-war period and 14,400,000 in 1926–30, an increase of 89.4 per cent.

These, of course, are the principal wheat-exporting countries of the world. Of some fifty different countries from which quite careful statistics are gath-

ered the average increase in acreage from the pre-war period to 1930–31 is 27 per cent.

In so far as the United States is concerned, there is still another factor that should be mentioned, namely, the decline in the per capita consumption of wheat. This decline dates from the beginning of the present century and amounts to some 20 per cent. It can be accounted for in part by changes in the diet of our people —an increased consumption of fruits and sugar, greater variety in the diet due to refrigerator transportation and cold storage and campaigns for the larger use of vegetables. The per capita consumption of meats has also declined during this period 7 per cent.

As a result of the increased acreage and consequent increased production of wheat, coupled with under-consumption, the world carry-over of wheat has been climbing upward, until in the United States alone it amounted to some 360 million bushels on July 1, 1933. This can only have a depressing effect upon prices.

The foreign market for the wheat crop of the United States is largely a thing of the past. Our exports of wheat in the nineties and in the early part of the twentieth century not infrequently amounted to considerably more than 200 million bushels per year. As an average of the five years immediately preceding the great war they had, however, dropped to 107,103,000 bushels. The war naturally made a great market for wheat and speeded up production wherever this was possible. Our exports for the three highest years of the war period averaged 330,806,000 bushels.

The price per bushel kept pace with this unnatural demand, reaching $2.13 per bushel as an average farm price in 1919. As a result of these abnormal conditions many agricultural prophets felt justified in predicting that this country would never see wheat as low as $1.00 per bushel again.

By 1926–30 our exports had dropped to an average of 174,765,000 bushels. This compares very favorably with our pre-war exports, if one did not know that there was a marked decline of many million bushels each succeeding year, finally dropping to an all-time low of 41 million bushels for the year ending July 1, 1933.

It would seem quite evident that we can not count upon much of an export market for our wheat in the near future at least. Great Britain, our best customer in the past, has been getting about one half of her imported wheat from non-British countries, of which the United States has had its full share, and one half from British colonies. This, however, was prior to the recent Ottawa Conference. If this conference means anything it must mean that Great Britain will in the future get a considerably larger portion of her wheat from the British commonwealth.

Other European countries have used large quantities of our wheat in the past. That market is rapidly disappearing also, The nationalistic spirit is everywhere prevalent; the determination to be as nearly self-supporting as possible has led many European countries to erect tariff barriers which virtually prohibit importations of wheat. These barriers range from 85 cents to $1.60 per bushel, which would seem to mean "keep your wheat at home."

The recent World Wheat Conference in London, in which most of the leading wheat-producing countries took part, attempted to reduce acreages in the wheat-exporting countries, to prevent further increases of acreages in wheat-importing countries and to allot the prospective demand for some 560 million bushels from the importing countries. The allotments were as follows:

Canada	200,000,000	bushels
Argentine	110,000,000	"
Australia	105,000,000	"
Danubian States	54,000,000	"
United States	47,000,000	"

The remainder was divided between Russia, Africa and Turkey. It should be said that Russia was not a party to this agreement. The allotment made to the United States means very little in the matter of providing a market for our normal surplus.

With this situation before it our Federal Government has undertaken to meet it by reducing our acreage to a point where it can be utilized in the main in this country, allowing for a normal carry-over of some 125 million bushels. The great problem was, and is, how to bring about a certain and definite reduction in acreage when nearly 6 million farmers who are scattered from ocean to ocean and from the Great Lakes to the Gulf are involved.

It is a comparatively easy matter for a dozen or more heads of corporations which are manufacturing a given line of products to get together, agree upon allotments and close their factories when their limit is reached. It is quite a different matter for the farmer to close his plant, turn off his principal helpers—his wife and children, by the way—when prices are not to his liking. With taxes and interest to be met, his only recourse seems to be to keep going and take whatever the conditions of the market provide.

Accordingly, the Federal Government has adopted what is known as the domestic allotment plan and has said to the wheat grower: Reduce your average acreage 15 per cent., and we will pay you 28 cents per bushel on 50 per cent. of your average crop for the last three years. This has made it possible for the grower to reduce his acreage without serious loss and has given him assurance that other wheat growers will make the same reduction. The handicap under which the farmer has been working is being lifted to an appreciable extent.

Attention should perhaps be called to some dangers attendant upon such wholesale attempts to adjust crop acreages. The wheat crop of the United States in 1933 was 40 per cent. below the five-year average production of 1926–30, owing to unfavorable weather conditions. What if this should be repeated this year? The answer is that our present abnormal holdover will take care of more than four such low-crop years. There is no immediate danger at any rate. The wide distribution of the wheat crop, both in the United States and in the world, makes anything like a wheat famine very unlikely.

Letting matters take their natural course has brought the farmer, and with him all industry, to a sorry plight. It would seem to be the part of wisdom to take a hand in directing the ship of state. Success to the new men at the helm.

THE SCIENTIFIC JOURNAL, 1665–1730

By SHERMAN B. BARNES
CORNELL UNIVERSITY

THE period from the invention of printing to the invention of the learned journal was a period in which the Republic of Letters was handicapped by inadequate facilities of intellectual communication and publicity. In proportion to the increase in authorship and in the multiplication of books the need for communication and cohesion among savants expanded beyond the power of the learned letter, with its defects of privacy, loss of time and irregularity, to fulfil. This need of scholarship combined in the seventeenth century with the rise of the sciences and of intellectual curiosity among the upper classes to produce the learned journal.

The founding of the *Journal des Sçavans* at Paris in January, 1665, was followed by a remarkable expansion of the learned periodical press. Three hundred and thirty periodicals were founded in seven European countries between 1665 and 1730, Germany leading with the publication of 182, Great Britain coming second with 51, and Holland third with 34. In France 30 and in Italy 23 journals were founded. In French Switzerland and in the Scandinavian countries five journals were respectively published. Some contemporaries complained of the confusion caused by the great number of journals, a confusion exploited by the founding of at least six journals which sought to save the time and money of the public by publishing only the best articles taken from other journals. Such predecessors of the modern "Readers' Digest" all said in effect to the public: "Read us, it is not necessary to read others because we give you the best." That the supply of journals outran demand is suggested by the scores of journals of which but one or a few numbers were published. The state was a factor in cutting short the life of many periodicals, especially in France, where the *Journal des Sçavans* alone occupied a privileged position. On the other hand the state prolonged the life of several periodicals, such as the *Acta Eruditorum* and the *Journal des Sçavans.* Other factors that probably contributed to the cessation of many periodicals were financial difficulties, the barrenness of literary output, the absence of sufficiently numerous reading circles to support a periodical, the burden of individual editing, the difficulty of building up correspondence, literary contacts and of obtaining material, the inferior, inaccurate, partisan, polemical quality of many journals which prevented their appealing to public taste, the deaths of editors or publishers and the difficulties of transmission and of circulation.

There is little doubt that the journals were widely read. In 1721 a contemporary remarked that "there is scarcely any literature better received by the public, nor read with more eagerness than that of journalists." Scholars found that journals provided a rapid means of information concerning the existence and nature of new books. Journals functioned as valuable canals of communication on an international scale. Periodicals helped to overcome the difficulty so often referred to in the letters of the seventeenth and eighteenth centuries of procuring books from foreign countries. Poor means of communication and the organization of the book trade on national lines made it difficult to have access to all books pub-

lished. Moreover, journals supplied the public with vernacular accounts of books unintelligible in their original Latin or foreign tongue. This fact is emphasized by the custom followed in many journals of translating even the foreign and Latin titles of books reviewed. A number of periodicals, such as the *Bibliothèque Angloise*, the *Bibliothèque Italique* and the *Bibliothèque Germanique*, were originated to give publicity to the literary productions of some one foreign country.

Among their other functions journals popularized learning. The cultivated gentleman, preferring to learn by conversation in salons, by lectures or by reading short clear summaries of learned subjects, doubtless welcomed the short article and book review of the journal as attractive reading and turned repelled from folio tomes. It became very common for journals to replace books. The large number of worldly men and women who sought to instruct themselves at this epoch found that the reading of a literary-scientific periodical allowed them to speak in the salons of recently published books without purchasing or studying them. This view of the function of the learned journal was widely held at this time. "Journals," declared Denis De Sallo, "have been invented for the relief of those either too indolent or too occupied to read whole books. It is a means of satisfying curiosity and of becoming learned with little trouble." There were at least thirty periodicals in this period which were primarily designed to popularize learning, most of them short-lived, and in addition to these avowed popularizers, all periodicals using the vernacular appealed by their cheapness, convenient formats, brevity, novelty and variety. Moreover, they enabled amateur writers to gratify the desire to see themselves in print and aided the indolent or busy man of affairs interested in science "to whom every great book is a great evil" to acquire a superficial learning. In 1699 a contemporary declared that "by the easy means of journals, which require very little reading, ignorant people speak and decide on everything today, with even more 'hauteur' than scholars."

It is interesting to note that of the 113 specialized journals which appeared in the years 1665–1730, 30 were devoted to natural science. Eighteen of them were general in scope, eleven were essentially medical, and one was devoted to mathematics and physics. In Germany, Holland, Scandinavia and England learned journalism was thus initiated. Moreover, the idea of specialized scientific journalism arose independently in England before the appearance of the *Journal des Sçavans*, since Henry Oldenburg was authorized by an Act of the Council of the Royal Society, March 1, 1664, to publish a scientific periodical as his own private venture. Only his own procrastination robbed Oldenburg of the credit of originating learned journalism. Moreover, Oldenburg may have been acquainted with an unexecuted plan of a weekly or fortnightly scientific periodical specializing in "Physicks, Mathematics, Mechanicks, Opticks, Astronomy, Medicine, Chymistry, Anatomy" extant in Hooke's handwriting in 1663. Only one science magazine appeared in this period in Italy and in Scandinavia, respectively, two in Holland, three in Great Britain, eight in France and fifteen in Germany. Fifteen of these serials were monthlies, five were annuals, one a semi-annual, one a weekly, one a bi-weekly, and the others were too irregular in their intervals of appearance to characterize them. Of the thirty science journals only six were connected with important academies of science. Three of the periodicals connected with academies had the most

continuous existence during this period, the *Philosophical Transactions*, the *Miscellanea Curiosa* and the annual of the Royal Academy of Sciences, founded in 1699. Nine science journals lasted less than a year.

That learned journalism was founded for the convenience of the world of scholars rather than for the general public is suggested by the early vogue of specialized periodicals. While the specialized magazine expanded the content of journalism, from the point of view of the general public the specialized periodical was to some extent a limitation to its participation in cultural movements by the use of magazines. In a word, so it may be argued, specialized journalism attracted certain types of savants, but repelled the public. Yet medical serials had some popular interest because of their publication of remedies for diseases and of their accounts of monstrosities and curiosities; and in an age when religious questions were vital, a wide public was provided for theological journals. And as anatomy and other sciences became more popular, a specialized scientific serial would conceivably have greater appeal, especially since the sciences had not yet become too abstract and complex for easy comprehension. It is also significant that of the thirty natural science periodicals only eight were written in Latin.

It was a characteristic of the science journals that they were composed primarily of original communications rather than of book reviews. The learned journal profoundly influenced authorship through the opportunity it afforded for the publication of short, original articles, discussing discoveries, experiments, observations, etc. The use of periodicals gave authors the advantages of economy, conservation and publicity. Fugitive pieces and short pamphlets on learned subjects were easily lost, causing scholars to withhold publication since "there are but few who have so much time to spare as to write huge volumes, and they know that flying sheets and sixpenny books are as soon lost as printed." Magazines aided authorship by affording cheap channels of publication. Papers would, moreover, be conserved for the benefit of scholars if published in journals. Bayle considered that the most important function of the learned periodical lay in persuading scholars "to make their thoughts public, which otherwise they would conceal in their desks, not wishing to print flying sheets singly." Journals were intermediaries through which a succession of remarks, attacks and replies could be published and noised abroad throughout the learned world. They afforded opportunities for continuous discussion and greater publicity than pamphlets, letters or books. Discoveries which might otherwise have remained unpublished or unknown were given rapid, effective publicity. Moreover, scholars found periodicals helpful as places in which to publish rectifications, denials, corrections, requests for information, documents, data or instruments, and announcements of projects.

By their criticisms and threats of exposing plagiaries, inaccuracies and other defects, by removing scholars from the condition of privacy and isolation, and by the vast panorama of objective learning which journals spread before savants, learned periodicals contributed to the sum total of the critical element in the intellectual life of Europe.

The natural-science journals only very gradually acquired a "critical personality" of their own. Since their content consisted of original papers, the opportunity for editorial comment was limited. Moreover, an ignorant and credulous public influenced many periodicals to publish chimerical and "marvelous" prodigies, monstrosities and wonders. Pierre Bayle once wrote that

journalists "were obliged to speak from time to time of various prodigies and miraculous events, because they learn of the spread of rumors concerning these events and they imagine that the public would complain of their negligence if they said nothing about them." In general, periodical criticism was retarded in this period by poor facilities of intellectual communication and the consequent need for full, impersonal analyses of books, the opposition of authors and learned opinion, which favored objective, impartial description of books without subjective comment, the caution and prudence of editors desirous to avoid offending authors and public, the influence of booksellers upon journals and the power of authority in church and state.

Nevertheless, journalistic "personality" colored several science periodicals. Jean Baptiste-Denis in his *Conferences sur les Sciences* carried on a polemic against the Aristotelian notion of a "faculté pulsifique" as the source of heart movement and of "vegetative souls" as an explanation of the growth of plants. In the *Philosophical Collections* Hooke attacked a method of flying proposed by Francesco Lana, consisting of a ship to be carried aloft by four copper spheres exhausted of air. Hooke argued that Lana did not provide for spheres of sufficient thickness to resist air pressure, unequal on unequal surfaces; therefore, the thickness of the copper used would have to increase in the same proportion to the diameter of the spheres, which would prevent making the spheres proportionately lighter than the air and proportionately strong. Antoine Parent's *Recherches de Physique et de Mathématique* aroused much hostility by its critical reflections. Several editors of science journals gave their periodicals a personal note by utilizing them to promote an "interested" publicity for their books, medicines and lectures. Thus Jean Baptiste-Denis defended and advertised in his *Conferences* a certain "styptic essence" of his invention. Nicholas De Blegny, supported by influential patrons at the court of Louis XIV, founded an Academie de Nouvelles Découvertes, at which public lectures in medicine, anatomy and surgery were given. De Blegny used his *Nouvelles Découvertes sur toutes les parties de la Médecine* (1679–81) to advertise not only the academy and public lectures, but also his books, medicines and office hours "for those who needed him." This periodical was suppressed at the desire of the Paris Medical Faculty in 1682, because De Blegny was an interloper upon its monopoly.

THE PHYSICAL GOETHE

By Dr. JAMES FREDERICK ROGERS

WASHINGTON, D. C.

GOETHE was a heroic figure physically, as he was mentally. At twenty "a more magnificent youth never entered the Strasburg gates" and "long before celebrity had fixed all eyes upon him he was likened to an Apollo. Once when he entered a dining room people laid down their knives and forks to stare at the beautiful youth. . . . His features were large and liberally cut, as in the fine, sweeping lines of Greek art. The brow was lofty and massive, and from beneath it shone lustrous brown eyes, their pupils being of almost unexampled size. The short aquiline nose was large, and well cut . . . the chin and jaw boldly proportioned and the head rested on a handsome and muscular neck."[1]

In stature he was rather above the middle size, but, though very erect, he was not really tall, as he was sometimes described. "His frame was strong, muscular, yet sensitive."[2]

From his father Goethe inherited his well-built frame, erect carriage and measured movement and by his mother he was endowed with a large fund of "animal spirits." From neither does he seem to have received much immunity from infection, and, though so healthy from the standpoint of physique, he was, like George Washington, who was similarly endowed, frequently attacked by bacterial diseases. The very abundance of his vitality led him in his younger years to extravagances of physical excess which had much to do with bringing on these attacks of illness.

Already at six years, Goethe was a vigorous specimen. He relates in his autobiography how he was set upon at school by three boys with switches. "Fighting in school time was severely punished, so waiting until the hour for lessons was over I grasped one of my assailants by the hair and hurled him to the ground, pressing my knee on his back; I caught the head of the second, who attacked me behind and nearly throttled him; with a dexterous twist I threw the third flat on the ground. They bit and scratched and kicked, but I knocked their heads together without mercy."[3]

At sixteen he was described as "in the bloom of health," but the student life of the next years was trying even for so robust a being, and at nineteen the round of "restless excitement; irregular living; heavy Merceberg beer; a cold caught when bathing; the unwholesome vapours breathed when etching on steel; perhaps too a chest affection he brought on himself by over-violent exertion; all combined to disturb the sensitive balance of his organization so violently, that one July night he was attacked by a violent hemorrhage. . . . Then a tumor formed on the side of his neck which was troublesome and long in healing."[4] The symptoms have been considered as due to tuberculous infection.

A year and a half later Goethe in a letter wrote, "However sound and strong one may be, in that accursed Leipzig one burns out as fast as a bad torch. Well, well, the poor fox-cub will, little by little, recover." It was uncertain whether or not he had consumption, but a few months later he wrote that "things are looking better."

[1] George Henry Lewes, "Life of Goethe," London, 1864.

[2] *Ibid.*

[3] *Ibid.*

[4] Düntzer, "Life of Goethe," London, 1883.

In December he was "attacked by violent internal pain; all the remedies tried failed to lessen his fearful sufferings. His mother in her utter need tried her old pious plan of opening the Bible with a sharp point. The text to which she opened, 'Thou shalt yet plant vines upon the mountains of Samaria,' filled her with joyous confidence. When the orthodox methods of the pharmacopoeia failed, resort was had to alchemy—a magic salt brought about, or was accompanied by, relief."[5] The pain lasted two days and for three weeks he could not leave his room. A new tumor formed on his neck and finally had to be lanced. But it was Goethe and no ordinary mortal who was sick, and he writes, "I have learned much in illness, that I could have learned nowhere else in life."

For a year and a half he lived a life of invalid seclusion, and in 1771, at twenty-two, he was still troubled with a cough, though in May he was able to dance from two in the afternoon until midnight, "almost without interval." In June he wrote, "I am pretty well in other respects, but one is but half alive when unable to fetch one's breath . . . exercise and fresh air do one good as far as anything does good." It was not many months, however, until he could resume his immense mental and muscular activities. He excelled in all kinds of sports. He was an excellent swordsman and rider. He had a passionate love of swimming, which December's cold could not arrest. He never tired of skating, and "all day long and deep into the night he might be seen whirling along."

"His love of Nature made him indifferent to luxury. . . . In many things he was unlike his nation: notably in his voluntary exposure to two bright wholesome things, which to his contemporaries were little less than bugbears—fresh air and cold water."[6] When rebuilding his Gartenhouse he lived in it or about it. "Wrapped up in my blue cloak, I laid myself on a dry corner of the veranda terrace and slept amid thunder, lightning and rain so gloriously that my bed was afterwards quite disagreeable."

The daily program of his young manhood is thus described by Lewes. "He rose at seven, sometimes earlier, after a sound and prolonged sleep; for like Thorwaldson, he had a 'talent for sleeping' only surpassed by his talent for continuous work. 'Till eleven he worked without interruption. A cup of chocolate was then brought and he resumed work till one. At two he dined. This meal was the important one of the day. His appetite was immense. Even on days when he was not hungry, he ate much more than most men. Puddings, sweets and cakes were always welcome. He sat a long while over his wine, chatting gayly to some friend or other. . . . He was fond of wine and drank daily his two or three bottles. This was, for a Rhinelander, a moderate amount, to which he became accustomed from childhood. The quantity he drank never did more than exhilarate him; never made him unfit for work or for society."[7] He later reduced his ration of wine and "often took neither wine nor punch."

By the time he reached forty the desserts had disappeared from his table and "even the customary coffee after dinner. His mode of living was extremely simple. Between eight and nine a frugal supper was laid, but he never ate anything except a little salad or preserves. By ten he was usually in bed."[8]

His was the temper of the wide-seeing philosopher which he was, and he once remarked, "You see how far I am from hypochondriac disquietude which sets so many men at variance with their places in life."

[5] *Ibid.*
[6] Lewes, *op. cit.*
[7] *Ibid.*
[8] *Ibid.*

He had some attacks of severe illness subsequent to the one described. At forty-six he was tormented by a swelling in the cheek, which with the means resorted to for cure affected his sensitive nervous system greatly, "yet he laboured without ceasing." A few years later he had "a violent and protracted cold, followed by erysipelas, a convulsive cough and difficult breathing." Two years later he was kept indoors for a considerable time with another violent cold. At fifty-six he was "very ill indeed with colic of the kidney," of which he had three attacks in as many months.[9]

Every two or three years one or other of these ailments returned to the attack, but Goethe did not allow his sufferings to interfere greatly with his work and his splendid constitution reacted for health between times.

"At seventy he was younger than many men at fifty" and at this age he was described as "of high stature, of strong robust build, the brownish hair slightly bleached, the brow high arched, the eyes still fresh and fiery, his complexion white and red. The features of the countenance were strong, the chin somewhat prominent, the neck considerably fleshy."[10]

"As a rule he rose at six o'clock, and partook of coffee immediately. At seven he summoned his secretary and dictated until eight, sometimes until half-past eight. Then he walked on the terraces or in the garden until half-past nine; then breakfasted. After breakfast he dictated again or went down into the garden, where he remained until half-past five, when he ate some white French bread and drank some wine. After that he stayed in his room or, in fine weather, paced up and down the gardens repeatedly. Sokell never found him seated when in the gardens. In the evenings he read the letters that had come and signed those that he had dictated during the day. He went to bed at nine or half-past nine and enjoyed deep and sweet sleep. . . . He was very temperate, and ate and drank by rule, and during all the time in Dörnburg enjoyed perfect health."[11]

"There was abundant life in the old Jupiter whose frame was still massive and erect; whose brow had scarcely a wrinkle of old age; whose head was still as free from baldness as ever. . . . Hufeland, the physician, who had made a special study of the human organization with reference to its powers of vitality, says that never did he meet with a man in whom bodily and mental organization were so perfect as in Goethe. Not only was the prodigious strength of vitality remarkable in him, but equally so the perfect *balance* of functions . . . no function was predominant, all worked together for the continuance of a marvellous balance."[12]

At eighty, "the old man showed unmistakably that he was old. His hearing became noticeably impaired . . . yet his eyesight remained strong and his appetite good . . . he presented a striking contrast to the earlier years, in his preference for closed rooms. The heated and impure atmosphere of an unventilated room was to him so agreeable that it was difficult to persuade him to have a window open for the purpose of ventilation. . . . he sat in rooms so heated that he was constantly taking cold."[13]

Yet still he toiled and after eighty he produced some important works. In his last years he led a very regular and secluded life, and he passed away in his chair at the age of eighty-three.

[9] Düntzer, *op. cit.*
[10] Lewes, *op. cit.*
[11] Düntzer, *op. cit.*
[12] Lewes, *op. cit.*
[13] *Ibid.*

SCIENCE SERVICE RADIO TALKS

PRESENTED OVER THE COLUMBIA BROADCASTING SYSTEM

COLOR CHANGES IN ANIMALS

By Professor EARLE B. PERKINS

DEPARTMENT OF ZOOLOGY, RUTGERS UNIVERSITY

THE ability possessed by several groups of animals to change their general body coloration and alter their color patterns has excited the interest of professional zoologists and nature students alike for many years. Almost every one knows about the chameleon and its many colors changing with fair rapidity from one shade to another in response to background color or nervous excitement. The true chameleon is a native of Africa and India and is seldom seen in this country, but in Florida the so-called chameleon, Anolis, is a fairly common color-changer well known to tourists.

When we look through the animal kingdom for this remarkable response, we find that many animals are unable to change their color even though their skin contains an abundance of coloring matter or pigment as it is called. Pigment of one color or another is found in every major group of animals, but only in a few of the higher groups of invertebrates and in the lower groups of vertebrates is this pigment mobile and controllable. For example, among the mollusks (which include clams, oysters, snails, slugs and squids) there may be no color changes at all, as in clams and oysters; or extremely slow color changes, as in snails and slugs; or extremely rapid color changes in the squid and octopus where the colors flash from one shade to another in rapid succession in response to nervous activity. Many crustaceans, such as shrimps, are able to adapt themselves by changing color in such a way that they become pale and transparent over a white background, very dark over a black background, and variously colored when over colored backgrounds. The process of adaptation may require from several minutes to an hour, but when completed there is a remarkable approximation to the background shade and color so that the animal blends with its surroundings and is made less conspicuous than other animals which do not have adaptive color control.

Among the vertebrates or backboned animals many of the fishes, amphibians and reptiles show responses to background color and pattern. The common flounder will not only approximate the color of the background on which it lies, but will cause its skin to be mottled with spots and patches of color to simulate those of the background. In the laboratory, flatfishes placed over a black and white checkerboard pattern will cause their body pigment to change in such a way that a rough checkerboard arrangement of light and dark areas will be produced. Among the amphibians the frogs are well able to change their bodily color from a pale yellowish green to a deep brownish black, depending upon the shade of the background. Several reptiles in addition to the chameleon also are able to bring about adaptive color changes, the horned toad (which is not a toad at all, but a true reptile found in the southwestern part of the United States) has been used as a subject for color-change studies because of its readily controllable color changes.

If we take a piece of the skin of any of these animals and examine it under the microscope we find that the pigment,

instead of being diffused or simply deposited in ordinary skin cells, is contained within special cells called chromatophores and these chromatophores are able to contract or expand under the control of the animal. When a chromatophore is contracted the pigment is reduced to a minute spherical mass, and when the chromatophore is expanded the pigment is spread out into branching cell processes which may interlock with neighboring processes of other chromatophores to form a network. In this condition the animal takes on the color of the pigment network.

Further examination shows us that usually there are several kinds of chromatophores in the same animal. Some contain black pigment, some red, some yellow, and there may be other colors. Then, too, there may be a layer of pigmented cells which is iridescent and diffracts and reflects various colors as does an oil film on water.

In the vertebrates varying shades and colors are produced by the degree of contraction and expansion of the chromatophores, by the contraction of an outer layer of color cells revealing a layer of expanded color cells beneath, by light reflecting from the immovable iridescent cells, or by all the pigment cells reflecting the light to produce a blended color. In the invertebrates there is usually only a single layer of color cells but these are of different colors; red, yellow, brown and black being commonest. In the crustaceans and mollusks a yellow color, for example, is produced by an expansion of the yellow cells and a contraction of all the others; red or brown body color indicates that the chromatophores containing these pigments are expanded to a maximum and the other colors are reduced to scattered points—mere specks of color which do not affect the general hue.

The squids are peculiar in that they produce their rapid color changes by a somewhat different means than do all the other color-changing animals. Here, pigment is contained in elastic sacs to which are attached many small muscles. When the muscles contract this sac is spread out over a large area and the pigment presents a large surface; when the muscles relax, the sac contracts to an inconspicuous spot. By rapid nerve action on these muscles the squid causes a symphony of color to be played on its skin, produced by a "color organ" evolved long before man himself appeared on the earth.

All these facts have been known to naturalists for a long time. Within recent years studies have been made on the inner mechanism which controls the movement of pigment, and these studies have led to some very interesting and important conclusions.

Early experiments on the controlling mechanism in color change activity indicated that the nervous system played an important part in bringing about the movement of chromatophores and, in fact, stained sections of these color cells frequently revealed nerves in actual contact with them. Furthermore, when a living nerve was stimulated artificially, chromatophore movements could be produced. So the general assumption was made that color changes are directly under the control of the nervous system. This conclusion seemed obvious in view of the fact that the animal's eyes are necessary for ordinary pigment movements.

More recently, however, we have been hearing much concerning control of vital processes by means of hormones, or humoral substances, which are secretions of certain tissues of the body that are carried in the blood and other body fluids. These substances have the power to control a great variety of bodily functions independently of, as well as in conjunction with the nervous system. We know a great deal concerning the secretion of the adrenal glands, and of the secretion of the pituitary gland, and of

the thyroid and the pancreas. New secretions and new effects are being discovered until it would seem that hormones are being produced for some specific purpose in nearly every tissue of the body.

So it was not surprising to find that chromatophores are caused to contract or expand under the influence of hormones—the same hormones in many cases that influence other bodily processes. If we inject adrenalin into the blood stream of a fish or a frog or a chameleon its chromatophores contract; inject pituitrin and they expand. Remove the pituitary gland from a fish and its pigment cells contract and remain so until more pituitary secretion is admitted to the blood stream, because the pituitary produces the substance that controls expansion; remove the adrenal gland and no more contraction by means of the adrenal hormone is possible.

When nerves leading to the chromatophores are cut, and when hormones are no longer allowed to come into contact with the chromatophores, they still may be induced to contract or expand by changes in light intensity or temperature. Certain drugs will also cause pigment movement under laboratory conditions.

One of the most unusual instances of hormone control was announced five years ago, when it was found that the stalked eyes of crustaceans contain a substance which, when liberated into the blood stream, causes the chromatophores of the crustacean to contract. In these animals, of which the shrimp is an example, the nervous system plays no part in color-change activity, so the control is entirely humoral. An extract of the eye-stalks can be prepared which will cause chromatophore contraction in the living animal or in isolated pieces of skin containing chromatophores. When the eyes are removed, the chromatophores expand, because no more contraction substance can be produced.

More recently the eye-extract has been injected into other animals which change color to see what the range of effectiveness of this new hormone might be. Injected into fishes it produced contraction of chromatophores, and, rather amazingly, produced expansion of the color cells when injected into frog tadpoles.

The interesting thing about these discoveries and experiments, in addition to solving some of the problems of animal color changes, is the fact that additional evidence is presented for the presence of well-developed hormone-producing structures among the lower animals. These structures make up what is called the endocrine system—a system of coordinating organs in the vertebrates as important as the nervous system in controlling vital processes. Within the last year Dr. G. H. Parker, of Harvard, has found that nerves themselves secrete a humoral substance which passes to the affected organ and sets it into operation. So it may very well be that all bodily control is ultimately humoral.

The endocrine system is highly developed and found extensively among the vertebrates, but until recently its presence was only suspected in the invertebrates. As yet very few endocrine substances are known among the invertebrates—the crustacean eye-hormone being by far the most spectacular. And, too, the fact that an invertebrate hormone is effective on vertebrate structures seems highly significant. The occurrence of such a substance in crustaceans which will produce color changes in fishes and amphibians points to a forerunner, in the evolutionary history of animals, of the more highly developed vertebrate endocrine system.

FRIENDLY GERMS

By Dr. W. LEE LEWIS
CHICAGO, ILLINOIS

THE words used in human speech are an interesting study in themselves. If I use the word "taste," in the sense of an appreciation of cultural things, you think at once only of good taste. And yet some wag very properly remarked of some one that, "He had lots of taste, only it was bad." "Luck" invariably implies good luck; as we say one is "out of luck," meaning things are going badly. "Smells" suggest bad odor, yet most flowers smell nice. And so when I say germs you at once think only of small, repulsive wigglers, invisible to the unaided eye, that bode no good for mankind.

In the case of germs or bacteria there is a reason for this first reaction that all germs are bad. Bacteria like the same foods that we like, and so we are eternally in competition with them to keep our foods from spoiling. We boil alive these small competitors of ours, we freeze them, we deprive them of their drinking water, and dose them with chemicals in perpetual dispute over the ownership of foodstuffs. Bacteria also attack us in person and give us diseases. In spite of all we have learned about them they persist surprisingly. Bacteria were the first settlers on this earth, antedating us by a few million years. They have been called our younger brothers. They are really our very great-grandparents. Small wonder they know how to survive with such long and varied experience behind them. In spite of all that the microscopes and the laboratory have revealed about them, there are probably as many germs to-day in kind and numbers as there ever were.

My purpose for the moment is to break a lance in behalf of the friendly germs, for there are good germs as well as bad germs. We have gained our impression of the invisible bacterial population about us, much as some future historian might judge our contemporary human population from a stack of current newspapers. The vicious members of the respective groups find the most publicity.

When you can not overcome a supposed enemy, the next best thing is to ally with him or merge, as we say in business. And so, as our knowledge of bacteria, their habits, diets, end products and life cycles, has grown, we have increasingly harnessed these brownie chemists to serve our purposes.

In their important service to man I would mention first the large group of bacteria that live in the soil and the water and destroy dead organic matter. These are the great public scavengers who seize upon the waste matter of civilization and resolve it into simpler forms. These simpler forms may be utilized as plant foods and so enter again the cycle of living things. As plants they become food for animals and reach their highest spiritual and intellectual expression in man. The life of a chemical element is just one great merry-go-round after another.

Consider the element nitrogen, present in all life forms from the cell of an amoeba to the brain of a great artist. First, nitrogen is combined as an inert salt called nitrate. Plant life utilizes nitrogen in this form and builds plant protein out of it. Animals eat plants and build their protein from plant protein. The operation is wasteful and all along the way these friendly bacteria of nature convert the waste nitrogen compounds back into nitrates where plants may again start them on the highroad of life.

With the growth of population it has become increasingly impossible to dis-

pose of domestic and industrial waste through natural waters and the soil. Sanitary engineers have accordingly taken a page from nature's book and utilized these bacterial scavengers in great municipal sewage disposal plants. Moreover, as is so often the case when man borrows an idea from nature, he improves upon it. And so the resolving processes carried out by nature on waste matter by friendly germs are made more efficient both as to time and space in modern city sewage plants.

Another interesting illustration of how these friendly germs respond to sympathetic cooperation is found in the legumes, that is, such plants as beans, alfalfa and clover. On the roots of these plants may be found little pellet-like nodules. These are the houses for friendly germs. They are accommodatingly supplied by the plant without injury to itself. The bacteria which dwell there in a happy cooperation with the plant catch the free gaseous nitrogen of the air and build it into nitrate which is basic plant food. That is why clover-like plants are grown and plowed under to enrich the soil. That is why the U. S. Department of Agriculture once distributed these little root bacteria to farmers to place on their clover seed for soil enrichment.

I need to mention the use of bacteria in healing the ills of humanity. Formerly the death rate from diphtheria, for example, was very high. Now, if taken in time, the antitoxin treatment is practically a certain cure. How is the antitoxin made? Diphtheria bacteria in the laboratory are set against diphtheria bacteria in the throat. They are grown in large quantity in a kind of broth. They are then filtered and the resulting solution of toxins injected into the blood system of a horse. Later the antitoxins thus formed in the horse are injected into the blood of the diphtheria patient to help him neutralize and overcome the toxins from the marauding diphtheria germs in his throat.

This is but one example of many antitoxins and sera that are to-day saving countless human lives. Thus under certain circumstances enemy germs may become friendly germs.

In the realm of foods, bacteria are used extensively. For example, in the dairy industry butter owes its delicate, pleasing flavor to bacteria which bring about subtle changes in the butter fat. Special sour milks, much prized by many persons, are made with pure cultures of certain bacteria. These special sour milk germs are believed to attack and overcome certain hitch-hikers in our alimentary tracts that occasionally commit improprieties. Cheeses depend upon bacteria for their special flavors. The high cheeses are largely predigested in this manner. Soy-bean sauce is made by a fermentative process involving germs.

The farmer chops green stock feed into his silo and lets the bacteria ferment it. It is a rich, appetizing and nutritious feed for live stock. Sauerkraut is distinctly a product fermented by bacteria from cabbage. Vinegar is made by a germ of questionable taste. Bacteria play a strong part in the curing of meats. Cured meats are placed in a sweet pickle for several weeks where bacteria serve in many ways to develop that unique flavor we all like in smoked ham and bacon.

Salt-rising bread involves the action of germs rather than the usual yeasts.

In other industries, such as the tanning of leather, the manufacture of certain commercial solvents, the preparation of rubber, tea, tobacco, indigo and cocoa, and the preparation of flax, hemp and jute, bacteria are pressed into the service of man.

Germs may even be used in the mining business, for it has been found that they can convert native zinc ores into soluble form by oxidizing the natural sulphide ore into soluble sulphate of zinc.

Germs may eventually be used to heat houses. This comes about from the fact that some germs like a good tropical

temperature, around 80° C. They are the real Californians and Floridans of the bacterial population. However, there is this difference, that, whereas the Californians and Floridans are reputed to have difficulty at times in controlling their respective climates, the heat-loving bacteria settle the matter by manufacturing their own climate. They attack the material in which they find themselves and break it down in such a manner as to produce heat. Thus, given a proper food material, they could produce enough heat for themselves and allow us to bask in the overflow.

How is it possible for a tiny subvisible organism like a germ to produce effects which are noticeable to a being so much larger, in fact billions of times larger than the germ itself?

Germs are so small that scores of them could dance on the point of a needle at the same time, and in fact often do.

There are many reasons why they can make such deep-seated changes in such large amounts of matter, but the reason most often neglected is a simple one. It is this: Their stomachs are all outside them instead of enclosed in their bodies, as is the case with higher organisms. In other words, if we eat a bowl of soup it is conducted to our stomach *via* the esophagus. We send out various ferments such as pepsin into this transferred soup to digest it. But we only digest that amount which we swallowed and which we will assimilate.

But suppose we drop a germ in a bowl of otherwise sterile soup. The volume of soup is tremendous in proportion to the volume of the germ. And yet the germ will send out digestive ferments into the soup which surrounds him. He will grow large on the soup so digested and absorbed. Finally he will divide into two germs like his former self only smaller. They in turn will each split by simple cell division into two more young germs. And so the process goes merrily on.

Eventually the soup will all be predigested from the germs' standpoint and all spoiled from our standpoint.

Thus it is that a germ digests for its own energy and building purposes an amount of food matter far in excess of its own body needs. Thus it is that a germ's stomach is all outside him, where a higher animal's stomach is inside him and so limited in the amount of food material it can transform.

The rapid multiplication of bacteria by simple cell division and their tremendous digestive capacity are the two principle reasons for their great power to transform matter.

Summarizing, then, I have tried to prove that just because he is a germ does not necessarily prove that he is bad. Many are benign and friendly to man and some of the so-called bad ones have been trained to defend us against their outlaw brothers.

They are public scavengers and employees of many an industry. They respond to the slightest sympathetic understanding and cooperation. They work night and day without pay. They demand neither sleep nor vacations and are fiercely energetic.

Men and germs have been long together on this earth and are growing to understand each other better every day. Who knows but some day they will be no longer enemies and little children will prattle kindly:

> I love to see a little germ
> And pat him on the head,
> So prettily he wags his tail
> Whenever he is fed.

MOSSES

By Dr. A. J. GROUT

BIOLOGICAL LABORATORY, COLD SPRING HARBOR, L. I., N. Y.

To the great majority of people, mosses will suggest two things, "moss-back," and the proverb, "Rolling stones gather no moss." People are continually asking me, "Of what use are mosses?" We can neither eat nor wear them, but certain kinds have been used to stuff beds on which to sleep. While mosses have some very practical uses, as we shall see later, one of their main values to humanity is an esthetic one. If mosses were suddenly removed from the landscape, people would wonder what was the matter, without being able to give an explanation as to why it had so suddenly become bleak and uninteresting.

Let us listen to what a famous poet, who wrote mostly in prose, has to say of mosses, "Veiling with hushed softness the dintless rocks, covering with strange and tended honor the scarred disgrace of ruin—to them, slow-fingered, constant-hearted, is entrusted the weaving of the dark eternal tapestries of the hills."

The freshness which delights the eye after a summer shower is in a large measure due to the magic transformation of dried-up brown mats of moss into cushions of living green. Some parched and scorching summer day get a mat of this brown, dry, dead-looking moss from a ledge or boulder, moisten it, and behold a resurrection such as happens with every passing shower.

Mosses are all small plants, for they have no vascular system for conveying liquids from the earth to the stems and leaves. Neither have they any true roots for absorbing moisture and minerals, hence they are condemned to be perpetual dwarfs, shriveling at the touch of the sun and reviving with the raindrops; but having a vitality and endurance so that they will grow on the bare rock or boulder or ledge, even in the arid mountains of the west, often so dry they will crumble to powder at the touch, yet springing to life and vigor with every rainfall. In many cases the powder of the crumbled plant, if moistened for a time, will sprout out into fresh new life. Some of these drought-enduring plants have become so hardened to the lack of moisture that they have retained their vitality on the herbarium shelves of the museum for several years and have started to grow when moistened.

The length of time which the spores of these mosses can survive has been tested, and one authority reports that spores seventy years old have germinated. This, however, is subject to doubt, but it seems probable they will live for at least a quarter of this time.

Young capsules with developed spores are rich in protoplasmic content. The young capsules of the hair-caps taste like the blood from a bitten tongue and doubtless contain a high percentage of nutrition. If I were starving in a wilderness where these capsules are found, I should certainly try eating them, either raw or in a soup, even though no one knows by experience what the after-effects might be.

More than once mice have raided my duplicates and eaten the spore-filled capsules. Mosses in the field are often found with many capsules eaten by insects or mice. However, mosses as a class are remarkably free from parasitic fungi or animal foes.

Many species have most delicate and ingenious devices for retaining moisture. The leaves of most mosses, especially those of moist habitat, are but one cell thick, but those of dry rocks and ledges

often develop a double layer of extremely thick-walled cells in the upper portion. This is to prevent evaporation.

In most mosses the lower leaf cells are large and thin-walled for absorption, especially those cells at the leaf angles of certain species, which look, under the microscope, like tiny bubbles. When it rains the mosses spread out their leaves to catch the moisture in their cuplike bases, where it is absorbed into the large thin-walled cells. As the weather dries them up, the leaves close up tightly to retain moisture within. The arrangement of leaves, like the shingles on a roof, also assists to keep in the previous moisture.

One of the most important economic services of mosses is due to this very power to absorb and retain moisture. The forests are given the credit for retaining moisture, preventing floods and keeping up a steady flow of water in the streams, but a very large part of the water-conserving power of the forests is due to the mosses which grow in the shade of the trees. In our climate the moist atmosphere of the forest shade is necessary for vigorous moss growth, but in the treeless mountains of England and Scotland the atmosphere is so moist that the mosses grow freely without shade.

The most efficient of these water-conserving mosses is *Sphagnum,* or peat moss. Its leaves are made like tiny sponges, most of the cells of leaf and stem being hollow with open pores. By accurate test, dry peat moss will absorb twelve to fifteen times its own weight of water. This makes some of the most absorbent species of peat moss one of the very best dressings for wounds. It not only absorbs wound drainage and pus but has an antiseptic action also. Because of these properties of absorption and antisepsis, peat moss is also very useful as a stable bedding, preserving all liquid fertilizer and preventing stable odors; also in packing the roots of plants for transportation. Live fish may be carried for long distances packed in this moss.

Peat moss and embedded vegetation in favorable locations, such as the Scottish mountains, form layers from three to twenty feet thick and in bogs formed from filling in small lakes, the peat is of unknown depths. Into these bogs plunge animals and men in hurried flight or by accident. Not only animals, but persons are preserved as fossils by its antiseptic power. Dana reports the finding in recent times in English peat bogs of horses and knights in armor of the period of the Wars of the Roses and in a most remarkable state of preservation. In another bog bodies of men dressed in haircloth of a prehistoric period were uncovered.

These bogs are more treacherous than quicksand and even to-day many persons perish in them. If you find yourself sinking in one of these bogs where there is no help and no escape for you, console yourself with the fact that in the far distant future you will make a most valuable museum specimen. Peat, when the firm part of the bog is cut in slabs and dried, makes a most delightful fuel, both as to heating efficiency and pleasing odor. Quantities of peat have been dug out of nearly every subway excavated in New York City.

Aside from the uses of peat above mentioned, and the water-conserving action of mosses, they also serve directly to prevent erosion and to aid soil accumulation. On the bare earth in the Carolina mountains, where vegetation has been removed by man or nature, one may frequently see lilliputian mesas formed by a matting of moss protonema which has held together the particles of earth when struck by the falling torrents of the summer showers.

The stones in the beds of our New England brooks are often covered with masses of sand and gravel, caught and held by the mosses which cover them.

The bare bones of our New England mountains have become gradually covered by mosses and lichens, which slowly creep inwards from the margin of ledges until they are covered with a thin layer of vegetation. Then ferns, grasses and other herbs follow. As the mat thickens shrubs spring up, and finally mighty spruces and pines which have only a foot or so of soil to sustain them. When a tornado topples these trees, one can see how little they had on which to subsist. Let fire spread through such a region, as has happened in the Adirondacks in recent years, and the soil itself burns, leaving stark and naked the skeleton of the landscape and destroying nature's patient handiwork of a million years. Meditate on this, you who carelessly flick cigarettes or leave unquenched picnic fires on our beautiful mountain sides.

Now that we have learned something of the part mosses play in nature and in human affairs, let us consider them from a botanical point of view. What are these mosses which we are to consider? Not the so-called sea mosses—they are marine algae, a much lower order of plant life. No true moss will grow in salt water or salt marsh. Not the ghostly Spanish moss of southern forests—that produces flowers and seeds. Not the long, pendant, gray mosses of northern forests—these are lichens, also a much lower order of plant life.

Mosses are small plants varying from one sixteenth of an inch to rarely eighteen inches in height. They consist of stems, bearing so-called leaves, which perform the functions of leaves, although they do not correspond to the leaves of the higher plants. These leaves, having abundant chlorophyl, are in most cases but one cell thick.

Mosses are spore plants, producing tiny one-celled spores instead of seeds, but they have very distinct sex organs. A single plant may be bisexual, like the rose or lily, or unisexual, as in the willow or most of the higher animals. Moss spores are borne in little pods called capsules, which are usually on a short stalk. In nearly all cases these capsules open with a little lid. Very often there is a long beak, like a handle, which aids in lifting the lid when the spores are ripe. Sometimes this beak may be nearly as long as the capsule itself, and a raindrop or a beetle can easily knock it off. Underneath this lid, around the mouth of the open capsule, is a tiny fringe, called the peristome, which aids in the distribution of spores. Microscopically, this is one of the most interesting structures to be found in nature, and the teeth of which the fringe is composed are often sculptured with intricate designs and beautifully colored, deep red or dark purple.

When moist, this fringe closes much like the flowers in the dandelion head and keeps the spores dry, and also prevents them from being deposited in a lump. As the peristome dries, it opens so that a passing breeze, the foot of an insect, or any other passing object may scatter the spores into the air. Some of the peristomes twist up like a rope in order to close, others simply fold up until they form a compact closed cone. Still others have an inner peristome with holes, and an outer row of teeth folds over these holes and closes them.

Mosses preceded the arrival of flowering plants by untold ages, yet they had developed much the same devices for spore distribution that flower-lovers know so well as the means of the distribution of pollen. Pollen, as the botanists tell us, is only a spore that has gone a little way on its development.

The capsules of peat mosses burst when dried by the sun, sending out a tiny cloud of spores several inches into the passing breeze, accompanied by a whispered but distinctly audible "pop." This is easily demonstrated by collecting

the peat moss when its capsules are ripe and placing it near a fire or in the sunshine.

A very common moss in New England has capsules which look like a grain of wheat with a little tube on one end. When the lid falls off it leaves this little tube like the mouth of a blowgun. When a beetle or a mouse steps on the capsule the spores are shot out onto its coat and are carried away to be scattered here and there.

Mosses of the *Splachnum* family have developed low tastes, catering to flies, much like the stinkhorn fungi and the carrion flower. These mosses grow only on dung or decaying animal matter. Below the spore cases some species spread out a bright-colored purplish or yellowish umbrella. This umbrella also secretes a carrion odor, which, in connection with the color, causes the flies to visit it and carry away the sticky spores. Other members of this family give off a secretion at the base of the capsule, which flies eagerly lap up.

The spores of the water moss, *Fontinalis,* are sifted through a trellis-like peristome to be carried away in the current. It is to be noted that with the exception of these two families the moss spores are dry and powdery like the pollen of wind-pollinated flowers.

Thus, as in the distribution of pollen, wind, water, animal and explosive force are used for distribution of moss spores and in the *Splachnum* family we have color, odor and something like nectar for attracting insects. It will also be noted that the foul odor of the animal matter induces the insects to carry the spores where they will develop. Flies have been observed to go directly from *Splachnum* capsules to fresh cow dung.

On moist soil, bark or rotten wood or even on moist rocks, the microscopic spores develop tiny green threads called protonema, which are very much like fresh-water algae. One may often see the soil in greenhouses and old fields covered with this green network. From these green threads arise leafy buds which become moss plants, thus completing the life cycle.

For one with imagination there is adventure and romance in moss study. The species new to North America collected at the summit of the North Carolina mountains; the rare species from the continental divide in Colorado; the mosses collected in northern Alaska by the botanist Frederick Funston long before the time he collected in Aguinaldo in the tropical Philippines; the mosses collected in the arctic wastes by Admiral Peary on his way to the North Pole; the memories associated with mosses collected from the tropical jungles of the Florida Everglades and in the mysterious wastes of the great Dismal Swamp, all these have the power to thrill the moss-lover.

Like an affection for the birds, the trees, the flowers, the rocks and the stars, an interest in mosses furnishes an incentive to out-of-door life and healthful recreation, inexpensive, free to all country dwellers and travelers, available at all seasons, in winter's snows or summer's heat.

RESEARCH IN THE BUREAU OF DAIRY INDUSTRY

By O. E. REED

CHIEF, BUREAU OF DAIRY INDUSTRY, U. S. DEPARTMENT OF AGRICULTURE

WE have heard that "agriculture is a basic industry" for so long that the full significance of the phrase was all but lost in its own reverberations until the depression disrupted economic stability throughout the world and seriously threatened standards of living everywhere.

Now the people of the United States are again coming to realize the basic importance of agriculture in our national welfare and its close relationship to their own individual prosperity. They now understand more fully why there can be no general national prosperity without a prosperous agriculture; such understanding forecasts a more intelligent support of our Federal and State agricultural research institutions by a united people seeking their own economic security. Our Government is wisely attempting to bring us out of the depression by "tailing up" the agricultural industry with the emergency powers of the new Farm Act, but the weakened "critter" will need the nutritious food of scientific research to keep it on its feet and to give it strength to weather future crises.

Scientific research has been of immeasurable value to every branch of agriculture in the past; from now on it will be needed more than ever, particularly in helping to meet inevitable adjustments in the changing and competing markets of the world. It is not enough merely to adjust the amount of production to the needs of the consumer; we must adjust other factors as well. Producing quality products, transporting and storing them to retain that quality, developing new kinds of products for specific markets and cutting the cost of production all along the line are problems and opportunities for agricultural science.

No field of agricultural research offers greater problems of beneficial results for all of us than dairy research—research which contributes to the development of a sound and prosperous dairy industry. Nutrition specialists have demonstrated that there can be no substitute for dairy products in our national diet if we are to obtain the maximum results in health and to perpetuate a virile race through properly nourished children. Furthermore, it is imperative from the standpoint of national prosperity that we build a sound and prosperous dairy industry, for dairy farming comprises the largest single branch of the agricultural industry. On 70 per cent. of the farms of the United States will be found one or more milk cows, turning the products of the soil into milk and cream for sale or for use on the farm. The nation's 25,000,000 dairy cows account for nearly one fourth of the total income received by farmers for the sale of farm products, an income that has a wonderful stabilizing effect on agriculture because it is more or less steady throughout the entire year. More than that, the dairy industry through its numerous branches provides a means of livelihood for countless numbers of people who are not on farms. It provides jobs and income for men who truck the milk to the creamery, for great numbers of men in dairy plants who make butter and cheese and

ice cream, for men who work in the condenseries, for others who bottle and distribute milk to city doorsteps, for men who load tubs of butter and cans of milk on trains and on ships.

In an effort to develop and establish a satisfactory dairy industry in the United States the Federal Bureau of Dairy Industry is engaged in a program of scientific research designed to bring about three principal results: (1) Greater efficiency and economy in the production of milk and in the manufacture of its products; (2) improvement in the quality of milk and cream on the farm and of dairy products in the factory; and (3) a wider utilization of dairy by-products. The successful attainment of these three results should go a long way toward lowering the cost of dairy production, increasing the consumption of dairy products, and increasing the prosperity of the dairy farmer, the manufacturer, and the distributor; and at the same time provide a greater portion of our people with dairy foods that are wholesome and economical.

The unit of production in the dairy industry, of course, is the cow; and much of our research has been directed toward improving her efficiency as a milk-making machine. We know from our study of thousands of records of milk production and cost of feed that the high-producing cow is the most profitable cow. She may eat more feed than a lower-producing cow but she returns more income per dollars' worth of feed. In 1931, for example, in dairy-herd improvement association herds on farms where butterfat was sold for 30 cents a pound, a cow that produced but 100 pounds of butterfat a year did not return enough to pay for her feed. But the cow that produced 150 pounds of butterfat returned enough to pay for her feed and $8 in addition. The cow that produced 300 pounds returned $38 in addition to her feed cost, or almost 5 times as much in income over cost of feed as the cow that produced only half as much butterfat. The cow that produced 500 pounds of butterfat returned $82 in addition to her feed cost, or more than 10 times as much income over feed cost as the cow that produced 150 pounds.

But the average dairy cow in the United States produces only about 180 pounds of butterfat in a year. Obviously then a great many of the 25,000,000 dairy cows in the country to-day produce less than the average, and thousands of them fail to produce enough to pay market value for the feed they consume. Furthermore these inferior cows continue to add their yearly quota of unprofitable offspring to the herds of the country. The dairy farmer has no way of knowing for certain whether a heifer born in his herd will be a profitable producer or not, until she has been milked for at least a year. By that time she will be close to 3 years old and will have cost him from $100 to $150 for her keep. It is estimated that more than one third of the 5 or 6 million heifers raised for replacements each year turn out to be unprofitable producers.

To eliminate the enormous loss caused by raising heifers that are predestined to be unprofitable producers, as well as to raise the per-cow producing efficiency of our herds, it is essential that we develop a scientific breeding plan which will assure the dairy farmer of consistent and uniform results from his matings. The many different ideas, theories and practises with regard to breeding high-producing animals have not accomplished uniformly good results. True, many high-producing individual animals have been developed here and there, and even whole herds have been brought to a high average level of production. But few if any individual breeders have been financially able or scientifically inclined to carry on breed-

ing experiments under "controlled conditions" or for a sufficient length of time to accurately determine the merits of their particular theories and practises. A practical breeding program involves more than a system of mating outstanding individuals. It involves a knowledge of many fundamental facts about heredity, health, nutrition and countless other phases relating to reproduction. And since such a program is obviously a national necessity its development has become a task for the government research worker.

The Bureau of Dairy Industry started the task of developing a scientific and practical breeding program in 1918 by making an extended study of existing theories and practises. Dairy breeders, like breeders of other live-stock, had for many years been divided into three schools of thought regarding the best system of mating to obtain desired results. One school advocated linebreeding, another close inbreeding, and the third would mate only unrelated animals. Along with these practises went a number of other ideas of breeding, the result being that farmers and breeders were working in a maze of theory without any scientific basis for guidance. Since no actual experimental work had ever been carried on under controlled conditions to determine whether one system was more likely to produce desired results than another, experimental breeding herds were established at the Beltsville farm and at various other field experiment stations to test the respective merits of inbreeding, linebreeding and outcrossing. Projects were planned to continue indefinitely, or until the results could be considered conclusive.

Students of genetics had by that time come to some rather definite conclusions about the laws of heredity. They saw little possibility of applying these laws to the breeding of dairy cattle, however. It remained for the bureau scientists to point out the application of the new knowledge of heredity in the selection of dairy sires. As a result of statistical studies, involving many production records of registered dairy cattle, they concluded that the most successful sire is one that is "pure," or homozygous, in his general make-up for factors that govern the transmission of high milk and butterfat production. The better understanding of heredity indicated that the best way to measure a sire's germinal make-up, or transmitting ability, is through a study of the production records of a large number of his daughters. The bureau scientists then reasoned that if a sire has demonstrated his ability to beget daughters all or most of which are better producers than their dams, this may be taken to indicate that he has a high degree of homozygosity, or "purity" in his germinal make-up, for the factors that determine high production. They reasoned further that the use of such homozygous sires in a herd, for generation after generation, would gradually build up the inheritance in the herd until it is fixed for a high level of milk production, a high butterfat test, or both, depending on the basis of selecting the sires.

Out of this new knowledge has come the so-called "proved sire" system of breeding, in which attention is centered on the use of sires that have proved their ability to sire daughters that are better producers than their dams.

For nearly 15 years now we have been selecting sires on this basis for the breeding herds at our various field stations, and we have made remarkable progress in developing strains or herds that are approaching purity in their inheritance for high production. Also during this time our experiments with inbred and outbred animals have indicated a most important principle, namely, that when a sire has proved, through the production performance of his daughters, that

he is homozygous for the factors that determine high production, he will transmit the inheritance for high production to all his offspring regardless of whether he is related or unrelated to the females with which he is mated. It also appears that such unrelated sires, within a breed, have the same factorial make-up for milk production. This is important, indicating that selection of sires need not be confined to the same family.

In our experimental herds we are using proved sires, generation after generation, without regard to their relationship to each other. At one station we are using Holstein sires that have proved that they possess an inheritance for a high butterfat test. We already have records on the daughters of the third proved sire used in this herd and these daughters have butterfat tests ranging between 3.7 and 4.0 per cent. It appears that we are well on the way toward fixing an inheritance for a 4 per cent. level in this herd.

As a result of our progress in developing pure-line-production herds and in spreading genetic knowledge, farmers and breeders are taking a keen interest in the use of proved sires to head their herds. At present, however, the number of bulls that prove to be genetically pure is very limited, but we have demonstrated that the sons of proved bulls can be used with greater assurance that they will transmit high production than untried bulls. As a part of our breeding studies at the various field stations, all young sons of proved sires are placed in farmers' herds in the vicinity of the station for the purpose of proving their transmitting ability. The 505 daughters of 52 young Holstein bulls loaned to farmers near the Huntley, Montana, station have production records that exceed their dams' records by an average of 1,601 pounds of milk and 69.15 pounds of butterfat. Of these 505 daughters, 384 exceeded their dams in milk production and 412 in butterfat production. The 76 daughters of 12 young Jersey bulls loaned from the Beltsville herd have records that exceed their dams' records by an average of 716.5 pounds of milk and 57.4 pounds of butterfat. Of these 76 daughters, 48 exceeded their dams in milk production and 58 in butterfat production.

Because great sires are few and far between, much of our research work is directed toward prolonging the active life of all known proved sires, or toward perpetuating their "superior germ plasm" in other ways. For that reason we are studying the factors involved in artificial insemination and in the preservation of bull spermatozoa. If sperm cells could be kept alive for a period of several days, semen from a great breeding sire could be used on females coming in heat later on, or it might be transported over long distances and used to inseminate a number of animals. To date we have been able to maintain the viability of sperm cells for 82 hours under laboratory conditions. Other research work has shown the importance of enforced exercise and of certain feeds, particularly sprouted oats, in maintaining fertility in aged sires. The average sire will not breed beyond the age of 10 years, but we have been able to keep a few fertile to the age of 16 years.

While we are attempting through breeding research to develop an efficient "milk producing machine" we are not losing sight of the fact that the economical performance of the machine depends to a great extent on the "fuel" or feed we supply. For many years the farmer merely gave a milk cow what feed he had handy, and let her do the best she could with it. Now we know, as a result of our research, that the kind and quantity of feed affect her efficiency, or profitableness, in three ways. Feed affects (1) the quantity of milk produced, (2) the nutritive properties of the milk, and

(3) the health and reproductive functions of the cow.

Roughages, which are the natural and cheapest feeds for dairy cows, until very recently had not received the attention from research workers that their importance warranted. Our studies in nutrition have uncovered some immensely interesting facts about the value of different kinds and qualities of roughage. It was long known that alfalfa hay contains much more protein and calcium than timothy hay, but we have found that alfalfa hay also contains other properties of nutritive superiority, particularly vitamin A. Furthermore, we have found that these properties vary not only with the kind of hay, but with the different grades or qualities of a hay. Feeding experiments indicate that the vitamin A content of No. 1 alfalfa hay is 4 times as high as that of No. 3 alfalfa hay, 10 times as high as that of No. 1 timothy, and 30 times as high as that of No. 3 timothy. Cows fed the year round on grain and No. 1 alfalfa hay will produce satisfactorily and yield large quantities of milk for periods of from 5 to 10 years at least, whereas cows that are fed on grain and No. 3 timothy hay will not only begin to throw premature calves and dead calves within 6 months but will usually die or become useless as dairy animals within 3 years.

Other research workers had shown that there is a close relationship between vitamin A and carotin, which is one of the yellow pigments of grasses and other forage crops. It is now known that this vitamin is formed in the body of the animal from carotin in the feed, and transferred to the milk. The carotin content of the feed therefore becomes of great importance in feeding dairy cows, not only to maintain their health and reproductive functions but to keep the vitamin A content of the milk high for human nutrition.

We now have evidence that the greener the hay the higher its carotin content, so we have recently started some experiments to determine the best methods of curing and storing hay in order to preserve its natural green color. So far we have found that hay stored in the absence of light and air and at a temperature near freezing for 8 months will lose no color. Artificially dried hay that had a low moisture content lost but little color when stored in the absence of light and air and at room temperature; and there was no excessive loss of color when it was exposed for 8 months to either diffused sunlight or air, or both. The naturally cured hays had less color and more moisture than the artificially dried hays and when stored in the absence of air at room temperature sustained a marked loss of color. Apparently, quick and thorough drying is the main factor in making hay that will have and retain a high color.

These investigations have not only shown the importance of improving the quality of roughage from the standpoint of the effect on the nutritive properties of the milk, but they indicate that the growing and feeding of good roughage to good cows affords the dairy farmer his greatest opportunity to reduce feed costs. Actual feeding experiments prove that roughage is more nutritious and more palatable when cut in the earlier stages of maturity than when allowed to ripen before cutting, and that the immature cuttings yield more protein per acre. We have also shown that immature grasses, in the form of green pasture, hay, or silage, are far superior to mature grasses in maintaining milk yield. Furthermore, crop production surveys have shown that the nutrients required for milk production are generally produced cheaper in the form of roughage than in the form of grain. In a feeding experiment at one of our field stations cows that were fed nothing but

DAIRY CATTLE BREEDING SCHOOLS POPULAR

BUREAU SCIENTISTS DEVISED THE HERDISCOPE TO EXPLAIN THE LAWS OF INHERITANCE AND THEIR APPLICATION IN DAIRY CATTLE BREEDING.

good alfalfa hay produced 75 per cent. as much butterfat as when they were fed heavily on grain, with roughage, and at approximately half the cost. This information suggests that dairy farming, in many instances, would be more profitable if the farmer would devote all or most of his land to pasture and forage crops, and feed grain only when the price of milk and the additional yield would warrant the purchase of grain.

A profitable dairy industry depends on other factors than efficient and economical production on the farm, however. The quality of milk and of its various manufactured products plays an important rôle, not only because the better quality products usually sell at a premium but because satisfactory quality exerts a favorable influence on total consumption of dairy products.

To be of the highest quality, milk must be clean and sweet, pleasing in flavor, and free from abnormal odors and undesirable bacteria. The first essential is that it be safe for consumption, that is, free from disease-producing bacteria. The tendency to-day is to pasteurize practically all milk sold for direct consumption. But this practise did not become established without considerable opposition at first. Pasteurization was first recommended for milk by a noted American health authority in 1889, nearly 30 years after Louis Pasteur, of France, had found that heating would prevent souring and abnormal fermentation in wine and beer. At first the heating of milk was done secretively and for the sole purpose of preserving the milk to save losses to dealers. The early objections were gradually overcome as many scientists studied the subject and provided fundamental knowledge on the bacteriology and chemistry of milk. In this work the Bureau scientists played an important part by demonstrating that, from the bacteriological standpoint, proper pasteurization leaves the milk in the condition of fresh milk pro-

DAIRY FARMERS STUDYING RESEARCH RESULTS

DELEGATIONS OF DAIRYMEN ARE A COMMON OCCURRENCE AT THE BELTSVILLE EXPERIMENT FARM, TESTIFYING TO THEIR INTEREST IN THE RESULTS OF DAIRY RESEARCH.

duced under sanitary conditions but with the danger from pathogenic bacteria eliminated. They also showed that approved methods of pasteurization produced no objectionable chemical changes in the milk. The process is to-day accepted by health authorities, scientists, and dairy interests as the best means of killing pathogenic bacteria in milk on a commercial scale.

Millions of gallons of milk are rejected from the fluid milk market every year because of undesirable feed flavors and odors. If such milk were accepted it would have a very detrimental effect on consumption, for it is a fact that the quantity of milk consumed is dependent primarily on its palatability. In the course of studies started 20 years ago to determine how to avoid these undesirable flavors and odors we found that the flavors and odors from feeds and weeds eaten by the cows pass through the body of the cow to the milk in the udder, instead of being absorbed directly from the air as was formerly believed. We found also that some feeds and weeds continue to impart their characteristic flavor to the milk for a much longer time than others, after the cow has eaten them. For instance, garlic, which is one of the most troublesome weeds in this respect, flavors the milk within a few minutes after the cow has eaten it, and the flavor does not entirely disappear for about 7 hours. In fact, garlic will flavor the milk when the cow merely inhales its odor. Other feeds, we learned, impart their flavors to milk for only an hour or two, so out of this knowledge we have evolved practical feeding practises by which dairymen can get the benefits of certain highly-flavored feeds, such as silage, turnips, cabbage, kale, sugar beets and the like, and yet produce milk that is normal in flavor and odor. Since most feeds impart their flavors to milk for only a few hours after feeding, it is possible to avoid their flavors by feeding immediately after milking and not before. That gives the flavors time to disappear from the body of the cow before the next milking. If the principles laid down by our research workers were followed more generally by dairymen it would add from 15 to 20 million dollars

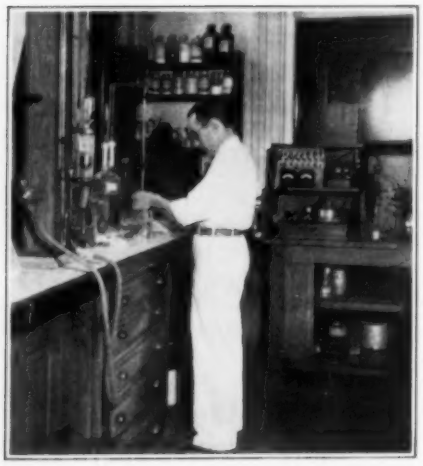
annually to the value of milk sold from farms.

Thirty years ago when we began our butter investigations the creamery industry was comparatively new. Less than one third of all butter made in this country was made in creameries, the rest being made on the farms. The result was a great variation in the methods of making and in the quality of the product. Nearly all butter held in storage developed fishy, oily or metallic flavors causing serious loss in value. Our early investigations showed that many of the deteriorations in butter were chemical in nature and that the acidity developed in the cream was an important factor in accelerating changes in the butter. The earlier practise, developed before pasteurization was generally adopted in the butter industry, was based on the assumption that a high acidity was necessary to inhibit bacterial action in the butter. Since the detrimental effect of acidity was shown nearly all factory butter is made from cream with a low acidity and the troubles from fishy, oily and metallic flavors have nearly disappeared. A large quantity of butter is now made from pasteurized cream without any ripening whatever. This is the so-called sweet-cream butter, which was first recommended by this Bureau for the navy, and which, on account of its superior keeping qualities, is especially adapted for shipment and storage. Such butter is known as sweet-cream butter, and is made from cream of low acidity in which the acid has been properly standardized. The improved quality of creamery butter, together with many other scientific developments in factory butter making, has been largely influential for the change in butter making from the farm to a factory basis. Today more than three fourths of all our butter is factory made.

Research by the Bureau's scientists has also played an important part in the great improvement in quality of ice cream in the last decade. In the beginning of the commercial ice cream industry the product contained a low proportion of those valuable materials in milk that are known as milk solids, and it was rarely ever made from pasteurized milk

EXERCISING BULLS AT BELTSVILLE

ENFORCED EXERCISE HELPS TO PROLONG THE ACTIVE LIFE OF OUTSTANDING DAIRY SIRES.



A DAIRY RESEARCH LABORATORY
FUNDAMENTAL RESEARCH, IN ADDITION TO PRODUCING RESULTS OF IMMEDIATE PRACTICAL VALUE, OFTEN PRODUCES INFORMATION WHICH LEADS TO UNEXPECTED DEVELOPMENTS.

and cream. Early in its studies of consumer preferences the Bureau found that most persons preferred ice cream rich in butterfat, sugar and milk solids not fat. However, when manufacturers attempted to increase the percentage of milk solids they had difficulty in making a product that was free from grittiness, or "sand" as the characteristic was termed. Research work on this problem indicated that "sandiness" was due to an excess concentration of milk sugar, which formed crystals when the ice cream was subjected to varying temperatures in the hardening rooms or in the dealers' cabinets. Methods have been developed by which a large percentage of the milk sugar in condensed skim milk can be removed. The resulting condensed skim milk, low in milk sugar content, can be used to increase the milk solids content of ice cream from the normal 10 per cent. to 12 per cent., without the danger of sandiness. If as a result of this work the average milk solids not fat content in ice cream should be raised by only 1 per cent. it would provide an additional market for 1,540,000,000 pounds of skim milk annually.

The manufacture of nearly all milk products is dependent on the control of the growth of bacteria. This control can not be exercised properly without a knowledge of the conditions which govern the growth, the activities and the death-rate of the bacteria. After many years of study and research in connection with these basic problems the Bureau scientists have recently perfected methods of making Swiss cheese of a quality equal to the imported product. Their investigations established the fact that the quality of Swiss cheese is dependent largely on the growth, at the proper rate and in definite sequence, of at least 3 species of bacteria. To help Swiss-cheese makers produce a high-grade product the Bureau now supplies cultures of these bacteria for making the right kind of starters. About 25,000,000 pounds of Swiss cheese is now made annually in this country and each year an increasing percentage is being made by the culture methods; and since the culture cheese ordinarily sells for 2 cents a pound more than non-culture cheese this research has a potential value of at least $500,000 a year to the dairy industry.

Such fundamental research, in addition to the results of immediate practical value, often produces information which leads to unexpected developments. In connection with these early studies on gas-forming bacteria in cheese, one of the Bureau scientists became interested in the effect of acid on the growth of bacteria. At that time it was customary to measure the acid in bacteria preparations by titration, although it was then known that titration measured the quantity rather than the intensity of the acid present. Physical chemists were aware that the intensity of the acid as determined by the dissociation of the acid.

and measured by determining the hydrogen-ion concentration, was of greater significance than the value determined by titration. The Bureau scientist pointed out the fact that the checking of bacterial growth in any kind of medium was due to the hydrogen-ion concentration, or acid intensity, and not to the titratable acidity; thus a few tenths of one per cent. of hydrochloric acid, which is strongly dissociated, would have the same effect on bacteria as 20 per cent. of a weaker acid like citric, which is only slightly dissociated. He developed accurate methods for measuring hydrogen-ion concentration and published a book on the subject which became the standard work throughout the world. He also synthesized a series of indicators by which hydrogen-ion determinations could be made quickly and accurately.

While this new understanding of the relation of hydrogen-ion concentration to the control of bacterial growth was the result of a Bureau worker's absorbing interest in "pure science" it has had a very far reaching effect in many industries. To-day the laundry industry controls the reaction of its wash waters and rinse waters by means of the indicators developed in the Bureau's laboratories.

This information also had an immediate effect on our other investigations of a practical nature. When the United States went into the world war there was a demand for a large amount of casein with a high degree of purity for use in making waterproof glue for airplane construction. The problem was referred to this Bureau and it was immediately determined that casein with a high degree of purity could be made by bringing the skim milk to a certain hydrogen-ion concentration, at which point the casein would be precipitated in small firm flecks, which would permit a thorough washing to remove impurities. The method proved to be satisfactory. Methods now in use in making commercial casein are based on the fundamental information developed at that time.

Along about this time we were also working on the molds involved in the ripening of Roquefort cheese. In studying the acid formation by these molds we found one that was exceptionally active in producing citric acid by the fermentation of sugars. By applying our knowledge of hydrogen-ion concentration we were able to control the growth of the mold by controlling the reaction of the medium on which it was grown, thus providing conditions favorable to the growth of this particular mold but unfavorable to the growth of contaminating bacteria. This was the first time that molds were used in commercial fermentation. A chemical company is now manufacturing a large quantity of citric acid by the use of this method, which displaces the citric acid formerly pro-

MAKING SWISS CHEESE

AMERICAN CHEESEMAKERS CAN NOW MAKE SWISS CHEESE OF AS GOOD QUALITY AS THE IMPORTED CHEESE BY FOLLOWING APPROVED METHODS OF BACTERIOLOGICAL CONTROL.

CASEIN USED FOR PAPER COATING

DAIRY SCIENTISTS, IN COOPERATION WITH THE BUREAU OF STANDARDS, HAVE DEVELOPED IMPROVED METHODS FOR MAKING PAPER-COATING CASEIN. THIS MACHINE IS IMPARTING THE SPECIAL FINISH REQUIRED FOR HALF TONES.

duced from citrus fruits and imported from Italy and Greece.

The third major field of research through which the Bureau seeks to enhance the profitableness of the dairy industry is concerned with the development of new ways to utilize dairy by-products. More than 3,500,000,000 pounds of milk solids are contained in the skim milk, buttermilk, and whey produced as by-products in the manufacture of butter and cheese each year. These by-products are often wasted or utilized so inefficiently that the returns to the producer are small.

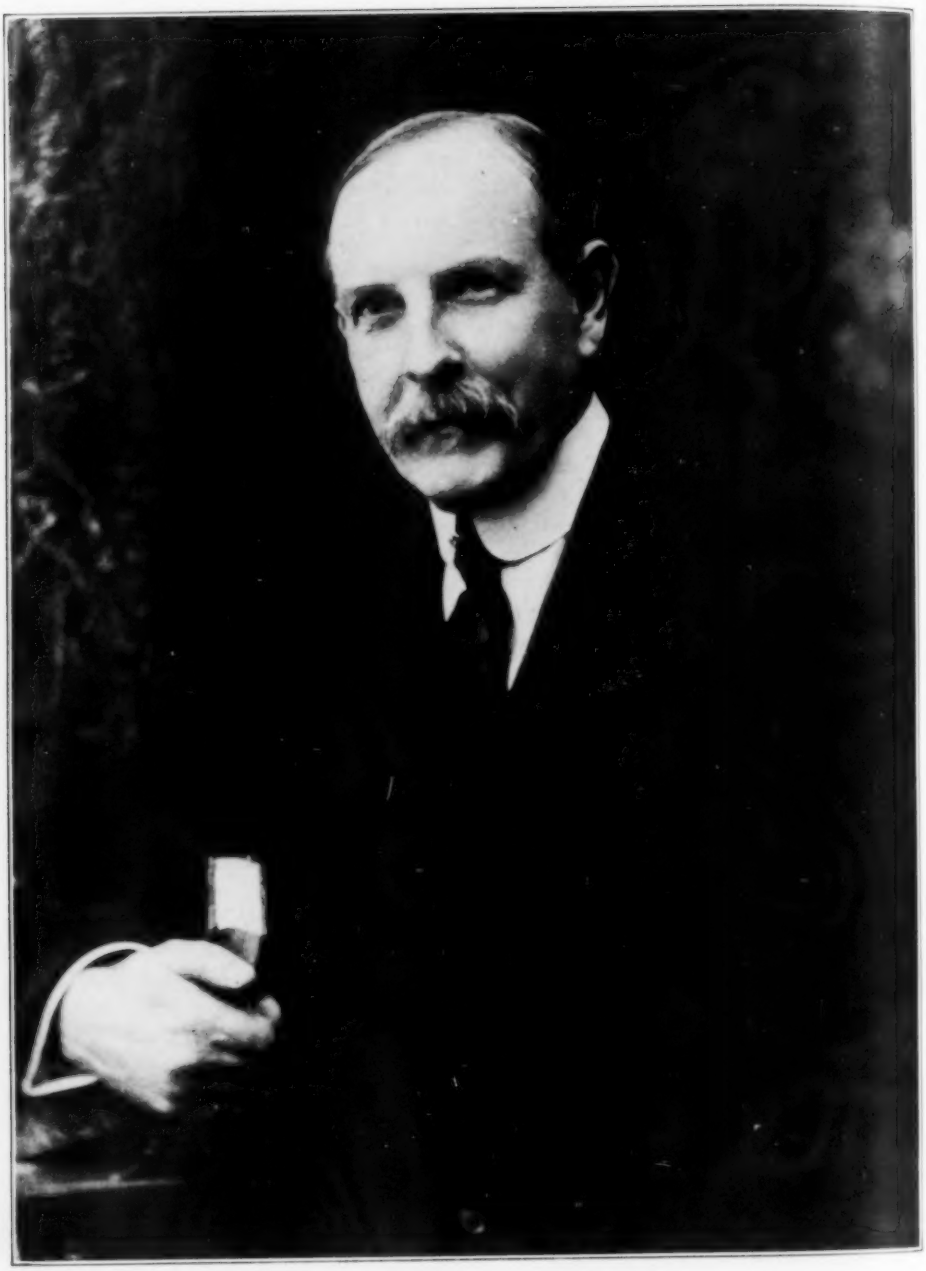
Considerable progress has already been made as a result of our research in the chemical and bacteriological phases of milk. Several years ago we discovered that certain difficulties in condensing skim milk to a point at which the acidity would be sufficient to make the product self-preserving could be overcome by using special high acid producing cultures. About 75 million pounds of skim milk are now converted into concentrated sour skim milk annually, a form in which it may be held indefinitely or transported long distances for feeding to poultry and hogs in sections where there is a shortage of dairy products.

We have also found that modifications in the methods of manufacturing skim milk powder will greatly increase its desirable effects when incorporated in bread and ice cream, and it is estimated that if all the bread were made with the most desirable quantity of skim milk

powder there would be a satisfactory market for all the skim milk produced in butter making.

The Bureau has long considered the possibilities of marketing much of our skim milk in the form of casein. Casein is used for many purposes, but more than 75 per cent. of all casein sold in this country is used by the paper-coating industry. Until the last few years more than half the casein used in the United States was imported, chiefly because our domestic product was inferior in quality. Domestic casein is now of higher quality and greater uniformity largely because of the information developed and introduced into commercial practise by the Bureau.

In the manufacture of cheese and casein, vast quantities of whey are produced and every 100 pounds of this whey contains from 4 to 5 pounds of milk sugar. The value of milk sugar as a constituent of baby foods and in the diet of patients suffering from intestinal disorders has long been known to medical science. Considerable quantities are also used in making medicinal tablets. The 12 million pounds manufactured annually is far less than could be produced if there were a greater demand for it and that is why we are endeavoring to develop new uses for this valuable milk solid. Milk sugar is not nearly so sweet as cane sugar, and this fact undoubtedly is responsible for its restricted use in the diet. A few years ago, however, one of our scientists perfected a method by which milk sugar can be recovered in a form that has a higher degree of sweetness and greater initial solubility than the usual commercial form. There is every reason to believe that the newer form has the same physiological effects as the older form and that it may in time supersede it as the milk sugar of commerce. There are many uses for milk sugar in the industries, as for instance in confectionery and in explosives, providing the sugar can be produced at a sufficiently low cost. The Bureau has developed methods by which a satisfactory grade of sugar can be produced at a cost materially lower than that of the ordinary pharmaceutical grade.



PROFESSOR ARTHUR E. KENNELLY

THE PROGRESS OF SCIENCE

THE PRESENTATION OF THE EDISON MEDAL TO PROFESSOR KENNELLY

THE Edison Medal of the American Institute of Electrical Engineers, which was awarded to Professor Arthur E. Kennelly in December, 1933, was conferred on him personally with appropriate ceremonies at the United Engineering Societies Building in New York on the evening of January 24. This medal was established by friends of Mr. Edison who had been associated with his developments of the incandescent electric lamp and systems for the distribution of electricity. Its purpose is to do honor to Mr. Edison's name and to celebrate further "Achievement in Electricity." It is one of the notably distinguished medals which are conferred solely in the engineering field and for distinguished achievement therein. The first Edison Medal was awarded in 1909 to Professor Elihu Thomson, who was followed as recipient in successive years by Sprague, George Westinghouse, William Stanley, Brush, Bell, Tesla, Carty, Lamme, Emmet and like distinguished contributors to our understanding of electrical phenomena and to the utilization of electrical power. Twenty-three of these medals have been conferred in a quarter of a century, there having been two omissions of annual awards.

The latest recipient, Dr. Kennelly, now emeritus professor both in Harvard University and in the Massachusetts Institute of Technology, was born in Bombay, India, in 1861, of British parents. His early education was in schools in England and Scotland. At the age of fifteen he became a telegraph operator in England and two years later took up work as assistant electrician of a cable station and thereafter became chief electrician in cable-laying work, which character of work has continued with him as a memory of heart's love. It was during these years that reflection and reading laid the foundation for his notable contributions to electrical engineering. Coming to this country in 1887, Professor Kennelly thereupon became identified with electrical engineering in America primarily, but his expanding reputation during the ensuing years has become international.

Professor Kennelly has been a profuse author in the field of electricity. Some of his writings have exerted a specific influence on the teaching of electrical engineering in certain aspects of electric circuit analysis, and these productions are well acclaimed by competent students in our engineering colleges and in the electrical industries. He has also been much sought after as a lecturer, here and abroad, as is witnessed by his professorships and his selection in the winter of 1921–22 as an exchange professor with France and in the autumn of 1931 as Iwadare lecturer in Japan. He is a member of many learned societies and has heretofore received many American and foreign honors. The memorable significance of his contributions to electrical engineering is well proved by his honors from his colleagues in that branch of learning. He was elected president of the American Institute of Electrical Engineers in 1898 and was reelected in 1899, in which post a second term is almost unique. He now is an honorary member of that society as well as the corresponding society of Great Britain and of France.

The Edison Medal was conferred on Professor Kennelly with the following citation: "For meritorious achievements in electrical science, electrical engineering, and the electrical arts as exemplified by his contributions to the theory of electrical transmission and to the development of international electrical standards." His authoritative writings in

THE EDISON MEDAL

electrical engineering have ranged over a wide area, comprising submarine cables, electrical communication apparatus, electrical machinery, electric circuits and radio communications. His endeavors have been exerted also in many fields aside from electrical engineering. These are exemplified, for example, by his strong advocacy of the adoption in this country of the metric system of weights and measures for manufacuring and commercial purposes. His international influence is well illustrated by his association for many years with the International Electrotechnical Commission, and by his now occupying the post of president of the International Scientific Radio Union as the successor of the greatly esteemed General Ferrié of France.

Electrical engineering in America is peculiarly indebted to Professor Kennelly, among other things, for his ardent support of the merits of hyperbolic trigonometry in electrical engineering computations and his continued industry from 1905 to 1915 in computing and publishing tables and charts of hyperbolic functions so as to fill the gap which then existed in such working data. Associated with this work were many illuminating geometric interpretations of the mathematical equations and equally illuminating discussions of mechanical analogies of electrical impedances.

D. C. J.

THE ADMINISTRATION OF THE WEATHER BUREAU

Willis Ray Gregg, former chief of the aerological division of the U. S. Weather Bureau, has been appointed by President Franklin D. Roosevelt to the position of chief of the Weather Bureau. Mr. Gregg brings to these greatly broadened responsibilities an ample educational foundation, obtained at Cornell University, where he received his bachelor of arts degree in 1903. To this he has added 29 years of intensive training and experience in actual Weather Bureau work. Beginning at the bottom as an assistant observer at Grand Rapids, Michigan, in 1904, he has risen to the top of his profession.

Having specialized in upper-air research during the last 16 years, he has at all times been in the front rank in serving the rapidly developing aviation industry. He is the author of an excellent text-book, "Aeronautical Meteorol-

ogy," which is simple enough for the amateur and the pilot, yet advanced enough to satisfy the technical student. He is a member of the National Advisory Committee for Aeronautics, the A. A. A. S. and numerous other scientific and philosophical societies. He has prepared many valuable papers of technical character. With his ripe experience, Mr. Gregg combines physical vigor, keenness of mind and a pleasing and forceful personality, that should serve him well in his new duties, which will be more largely administrative than scientific.

Dr. Charles F. Marvin, retiring from the chiefship of the bureau at the age of 75, impresses one as too valuable to be retired. Both Presidents Hoover and Roosevelt shared this opinion and continued Dr. Marvin more than five years beyond the usual retirement age. He will be retained as an associate of Mr. Gregg to assist him in grasping the reins of this complex bureau until Dr. Marvin soon rounds out an even half century of Weather Bureau service. An adequate account of Dr. Marvin's valuable service to the people of the United States in these 50 years would require a book. His first college degree was attained in mechanical engineering at Ohio University in 1883. Most of the instruments now used by the Weather Bureau were devised or perfected by Dr. Marvin. His thorough training in mathematics and physics has ever kept him in conservative lines, not easily disturbed by superficial theorists and quacks who are always getting the newspaper headlines with untenable methods of weather forecasting and condemning the Weather Bureau because it does not adopt their "new" methods.

Dr. Marvin has endeared himself to all his staff of workers, in and outside of Washington, by his humanitarian treatment and his patient hearing of proposals, suggestions and complaints. The many heartbreaking orders that had to be issued to faithful subordinates during the last two years are generally regarded by the men affected as part of the exigencies through which the country is passing and not the fault of their revered chief.

A committee of the Science Advisory Board, set up by President Roosevelt in 1933, was assigned to Weather Bureau problems. Its report, recently handed up through the Secretary of Agriculture to the President, noted that Weather Bureau service probably touches the daily lives of more people

CENTRAL OFFICE OF THE U. S. WEATHER BUREAU AT WASHINGTON, D. C.

DR. C. F. MARVIN
RETIRING CHIEF OF THE UNITED STATES WEATHER BUREAU

than all other federal services combined, with the single exception of the postal service.

The Weather Bureau has always been cognizant of the three-dimensional nature of its atmospheric problems and, by the use of kites, balloons and finally airplanes, has sought to bring together upper-air data of sufficient quantity and promptness. Airplane observations have proved most dependable, but it costs about $10,000 a year to maintain one flight of required altitude daily at a single station. Weather Bureau appropriations provide for only four airplane stations. The committee arranged tentatively for cooperation with the Army, Navy and technical schools so that the number of such stations will be increased to about 25 as a beginning, and it is hoped that others may be added.

With these improved facilities it will be possible to reach the dignity of "Air Mass Analysis," a new term coined to celebrate the acquisition of better data and the achievement of better methods of forecasting. Gradually, the new method will be introduced as the data become available and personnel can be trained. There is also the possibility of

WILLIS R. GREGG
NEW CHIEF OF THE UNITED STATES WEATHER BUREAU

monthly or seasonal forecasts when the climatology of higher levels has been established up into the stratosphere with something of the same completeness as that at the surface of the earth.

With a decrease in appropriations of $1,587,836, or 35 per cent., in the last two years, in the face of continually increasing demands for service, the new chief is confronted with extraordinary administrative problems. Aviation is particularly helpless without adequate Weather Bureau assistance, yet aviation can not be fully served with the funds available without drawing from the services to agriculture, engineering, commerce and general transportation, though all, particularly the engineers, are clamoring for more service. Many important stations are undermanned and the standards of salary and training have been lowered at a good many vital places. The personnel have borne the larger part of the curtailment, so far, but if some great weather catastrophe should occur, the public might pay large toll. It can be shown that Weather Bureau service to agriculture has saved as much as $100 for every dollar the service cost.

CHARLES D. REED

FRITZ HABER

DISTINGUISHED GERMAN CHEMIST, WHO DIED IN SWITZERLAND ON FEBRUARY 1. UNTIL LAST YEAR PROFESSOR HABER WAS DIRECTOR OF THE KAISER WILHELM INSTITUTE FOR PHYSICAL CHEMISTRY AND ELECTROCHEMISTRY. IN 1919 HE WAS AWARDED THE NOBEL PRIZE IN CHEMISTRY FOR DISCOVERING THE "HABER-BOSCH" PROCESS FOR THE FIXATION OF ATMOSPHERIC NITROGEN.

MAN—PAST AND PRESENT—IN THE FIELD MUSEUM

DURING the summer of 1933, the Field Museum of Natural History, Chicago, opened two new large exhibition halls in the Department of Anthropology. The Hall of the Stone Age of the Old World presents the story of man's evolution and development during prehistoric ages, by means of eight life-size diorama groups and fifteen cases of archeological material. In the Hall of Races of Mankind, 100 life-size bronze sculptures (full-length figures, heads and busts) portray typical members of the great racial divisions of the human family living to-day.

In the Hall of the Stone Age of the Old World the first of the groups presents a moonlight scene in northern France during Chellean times, 250,000 years ago. Beside a meandering river two hunters have built a fire, while on the opposite bank the great animals of the time are watching the flickering light. The dim and shadowy scene suggests the incompleteness of our knowledge of that early period.

Group II shows a Neanderthal family at the entrance to Devil's Tower rockshelter at Gibraltar. Group III portrays the dawn of art, magic and religion. Here an Aurignacian artist is kneeling before the frieze of mutilated hands in the cave of Gargas in southern France. Group IV shows a Solutrean sculptor of mongoloid type carving a horse on a block of limestone in front of the frieze of pregnant animals at Le Roc, Charente. In a smaller case is a reproduction of the Tue d'Audoubert bisons of clay; and opposite is the original Cap-Blanc skeleton of a young Magdalenian girl. Group V is a natural size reproduction of the Cap-Blanc rockshelter in the Dordogne district of France. Group VI portrays an Azilian boar hunt at the entrance to Mas d'Azil, Ariège, emphasizing the first domestication of the dog. Group VII shows the great Alignment at Carnac in Brittany, where a priest of the Neolithic age, with arms upraised, worships the sun as he welcomes the birth of a new day. The final diorama of the series is an early morning scene at Lake Neuchâtel, Switzerland. Two fishermen are dragging a large seine to shore, and a typical Swiss lake-dweller village is painted in the background.

The life-size human figures and the installation of each group are the incomparable work of Frederick Blaschke, who obtained assistance from Sir Arthur Keith, Professor G. Elliot Smith and the Abbé Henri Breuil. His results are therefore as accurate as present knowl-

FIELD MUSEUM OF NATURAL HISTORY, CHICAGO

CHELLEAN MOONLIGHT SCENE IN NORTHERN FRANCE, 250,000 YEARS AGO[1]

edge warrants. Charles A. Corwin, staff artist of Field Museum, is responsible for the remarkable painted backgrounds.

The archeological material includes the type collection from Solutré and many other important treasures, all of which were acquired by me with the cooperation of the Abbé Breuil, who assisted me in planning the hall. There are also tens of thousands of archeological objects available to students in the study collections of the Department of Anthropology. The work on this hall, begun early in 1927, was completed in August, 1933.

The Hall of Races of Mankind was planned to show the main divisions of the human race assembled together in one great exhibition hall for the purpose of study and comparison. Breaking away from the traditional museum schemes for presenting physical anthropology exhibits, a great sculptor, Malvina Hoffman, was employed for this important task. The eminent English scientist, Sir Arthur Keith, was keenly interested in the project, and gave Miss Hoffman much valuable advice in her work. She traveled around the world in

[1] The illustrations in this article are reproduced through the courtesy of the Field Museum of Natural History.

CHAUNCEY KEEP MEMORIAL HALL

WITH BRONZE FIGURES OF RACIAL TYPES OF MANKIND, BY MALVINA HOFFMAN, SCULPTOR.

search of models, and everywhere received assistance from qualified anthropologists.

The hall is arranged in the following manner: The center is dominated by a symbolic group of heroic size, the Unity of Mankind, representing the three main branches of the human race—a black, a white and a yellow man. Around the walls, set in alcoves, are the main variations within these three groups, geographically arranged by continents. In the African section the family groups of Kalahari Bushmen and Ituri Pygmies are valuable from an esthetic as well as an anthropological point of view. There is also a tall young Shilluk warrior, resting on one leg in the curious stork-like pose characteristic of his people. In striking contrast to his serious mien, is the beautiful Sara girl poised in the graceful attitude of a rhythmic dance.

In the European section there are full-length figures of Nordic and Mediterranean types. The representatives of Asia include a Veddah, Kashmiri, Tamil, Andamanese, Tibetan, Chinese jinriksha coolie and an aged Ainu. From the Pacific area, a Hawaiian surf-rider, a Solomon Islander, Semang pygmy with blow-gun, an Australian family group and a Malayan cock-fighting group are shown. It is impossible here to describe the numerous other types represented in this hall.

NEANDERTHAL MAN
RESTORED BY FREDERICK BLASCHKE, SCULPTOR.

A BLACKFOOT INDIAN
BY MALVINA HOFFMAN, SCULPTOR.

In her sculptures Malvina Hoffman combines realism with artistic power. In the words of Sir Arthur Keith, "Malvina Hoffman is a great sculptor who lavishes her art in the service of anthropology." Students and visitors owe a debt of gratitude for her great contribution to art and science.

A small section at the east end of the hall will be devoted to exhibits dealing with the more technical aspects of physical anthropology. These will include variations in stature, color of eyes, skin, hair, etc. The effects of epidemics and disease on populations, as well as demography, will be illustrated.

These two halls were planned and directed by me in cooperation with Dr. Berthold Laufer, curator of the Department of Anthropology.

HENRY FIELD,
Assistant Curator of Physical Anthropology
FIELD MUSEUM OF NATURAL HISTORY

HIGH ALTITUDE WEATHER OBSERVATIONS

PLANS for a study of weather conditions in the stratosphere by means of sounding balloons carrying delicate recording instruments, with supplementary high altitude observations by airplane, were recently announced at the Massachusetts Institute of Technology. Professor Carl G. Rossby, director of the meteorological laboratory, will direct the new stratosphere studies from the Lambert Field Airport at St. Louis.

Forty balloons, which are about four feet in diameter when inflated, will be released from this observation post. They will carry specially designed instruments weighing only a few ounces each, which will automatically make records of temperature, humidity and atmospheric pressure. The balloons will rise many miles above the earth and will burst in the rarefied air of the stratosphere. The instruments will be enclosed in bamboo shock-absorbing frames, and the fluttering fragments of the broken balloon are being relied upon to break their speed of descent.

Many of the balloons are expected to reach an altitude of twelve miles above the earth. They may be carried great distances by wind currents, and each balloon will bear an identification tag offering a reward of $5.00 to the finder, provided the instruments and their records are not tampered with. Further instructions will advise finders how to care for the instruments until Professor Rossby sends a special shock-absorbing container in which to ship them to his laboratory.

A mid-continental location for the experiment was chosen in the hope that most of the instruments would be found on land. To carry out the study in New England, where the prevailing winds are from the west, probably would result in the loss of most of the balloons at sea. These upper-air observations are expected to contribute to the knowledge of meteorological conditions in the atmosphere and to advance studies of weather forecasting. This research program has been made possible by a grant of over $8,000 from the Rockefeller Foundation.